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Energy Storage Valuation Tool Draft Results

Investigation of Cost-Effectiveness Potential for Select CPUC Inputs and Storage Use Cases in 2015 and 2020

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EPRI Energy Storage Program

CPUC Storage OIR Workshop (R.10-12-007)
3-25-13

My Garage

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My Garage – An Asset Utilization Case Study

My garage is filled with expensive, underutilized assets.

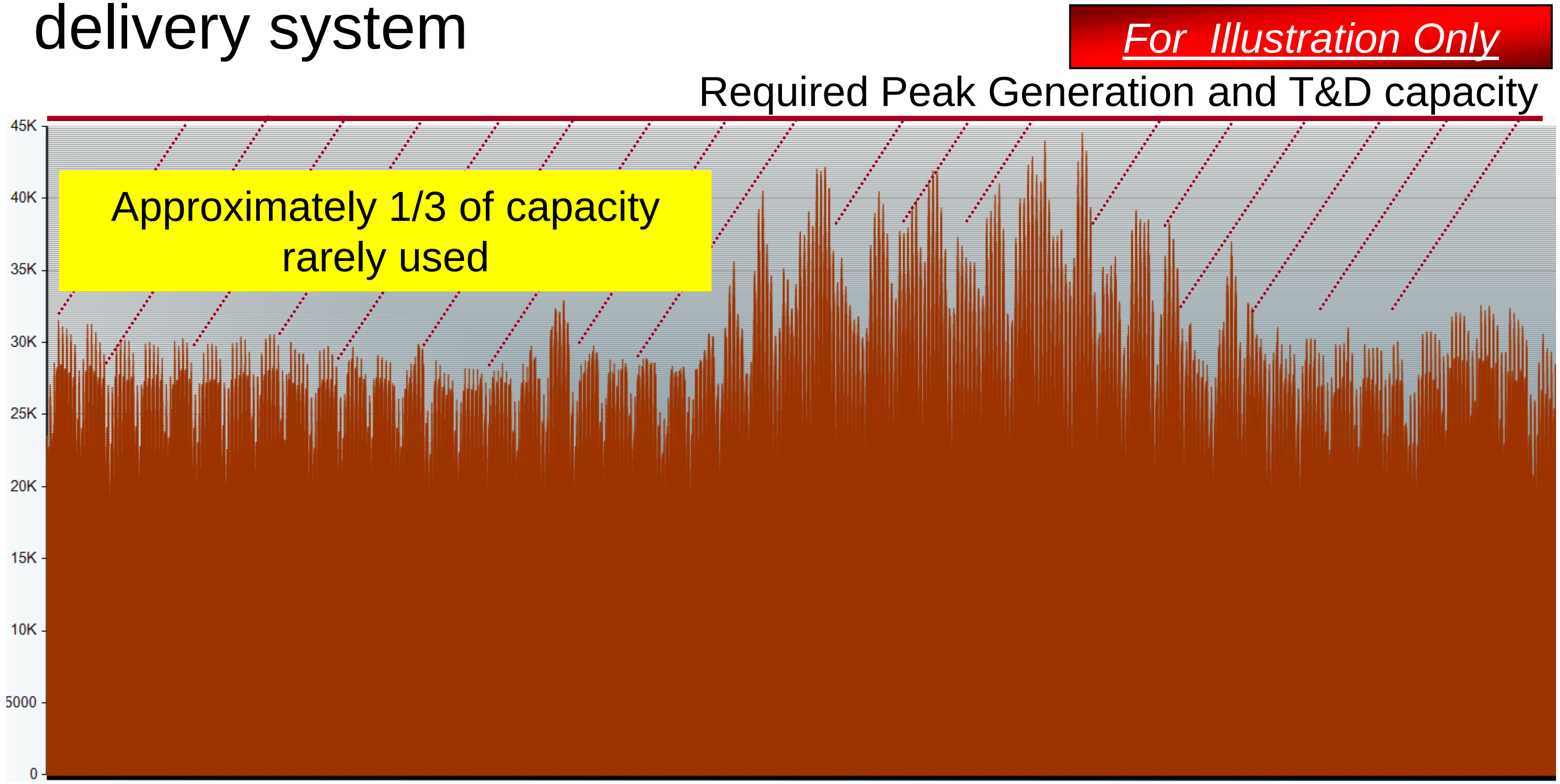
New Industries are Emerging to Address Low Asset Utilization

- Underutilized assets leave a lot of money on the table
- Improved communication and information has lowered transaction costs and enabled new markets

Photo by: Ben Kaun

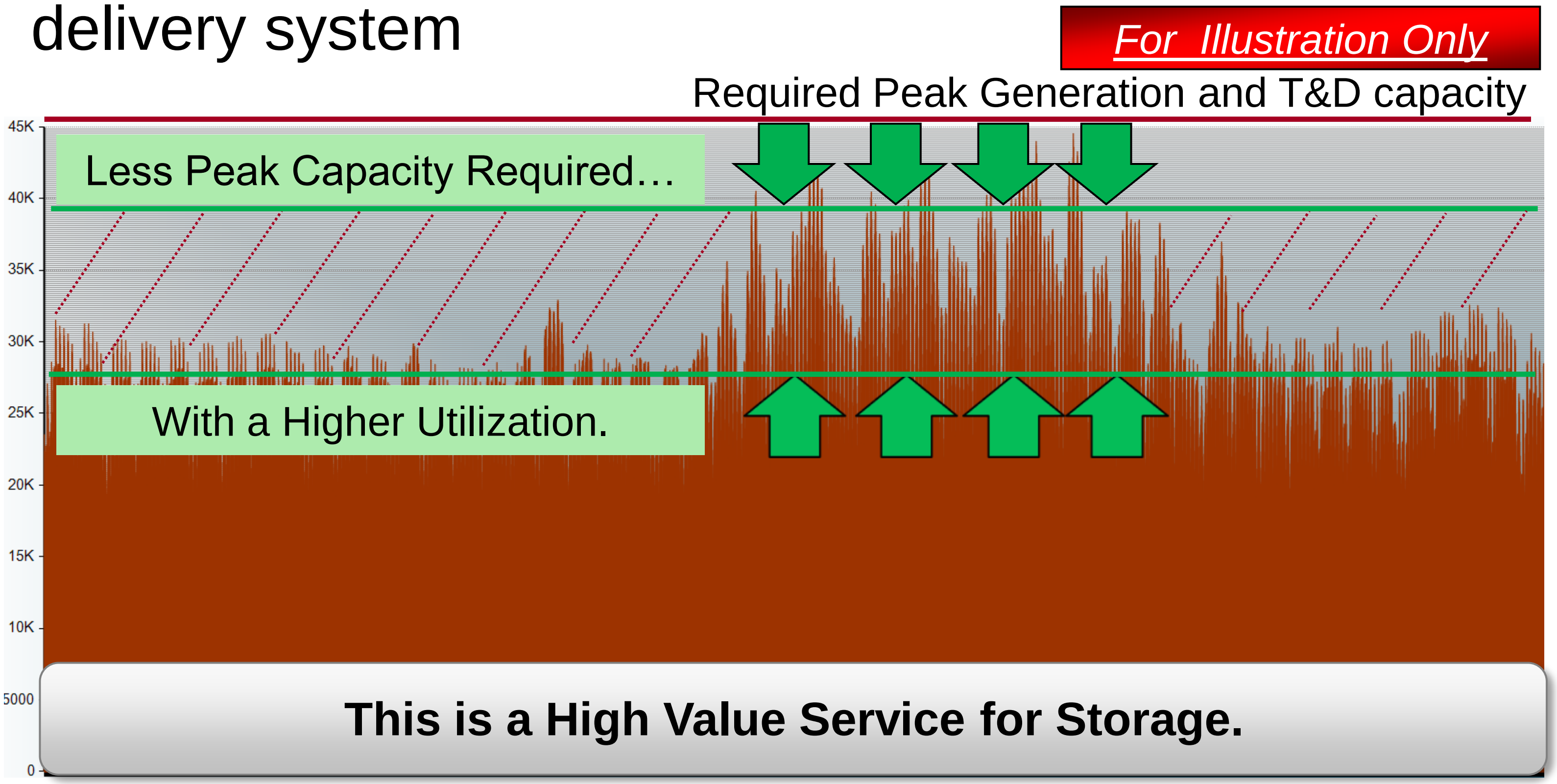
Peaky Loads Cause Utilization Issues for Electric Systems

- Not just generation, but the entire T&D delivery system
- Storage could shift load from off-peak to on-peak load periods to avoid additional peak generation and T&D delivery system



Energy Storage Can Help

- Not just generation, but the entire T&D delivery system
- Storage could shift load from off-peak to on-peak load periods to avoid additional peak generation and T&D delivery system



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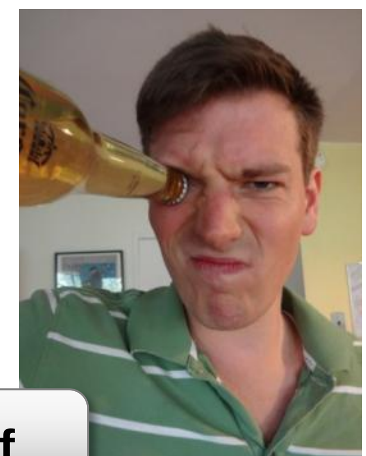
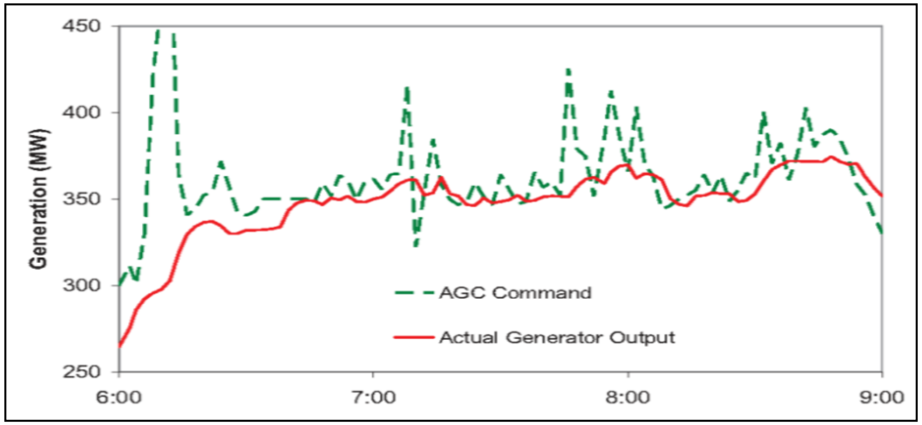
The Bottle Opener – An Elegant Tool

The Bottle Opener - Alternatives exist, but they are less well-suited

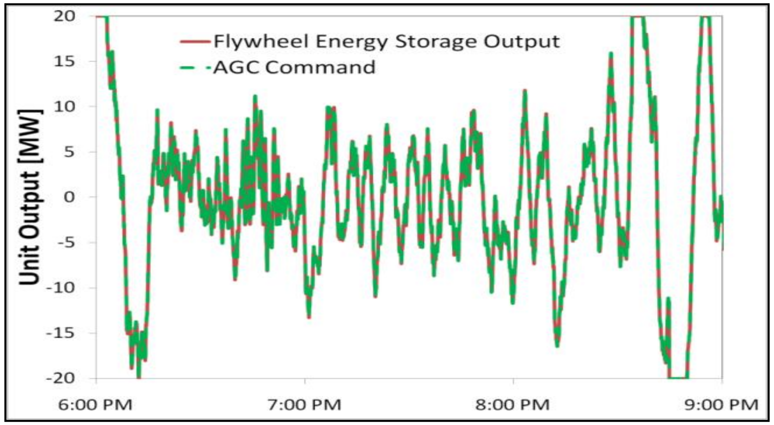


Other options are awkward and may damage the tool itself.

Frequency Regulation – A niche, challenging service for conventional grid assets



Slow Ramping of Conventional Generator



Flywheel / Battery Energy Storage Example

Sources Kirby, B. "Ancillary Services: Technical and Commercial Insights." Wartsilla, July, 2007. pg. 13

- Fossil generator has slower response and ramp than required, and has opportunity cost of lost energy sales
- Storage can provide not only its generating capacity, but also its load to balance the system frequency
- FERC755 (Regulation Pay-for-performance) is planned for implementation in 2013 and may increase current CAISO Regulation prices when implemented

This is a High Value Service for Storage.

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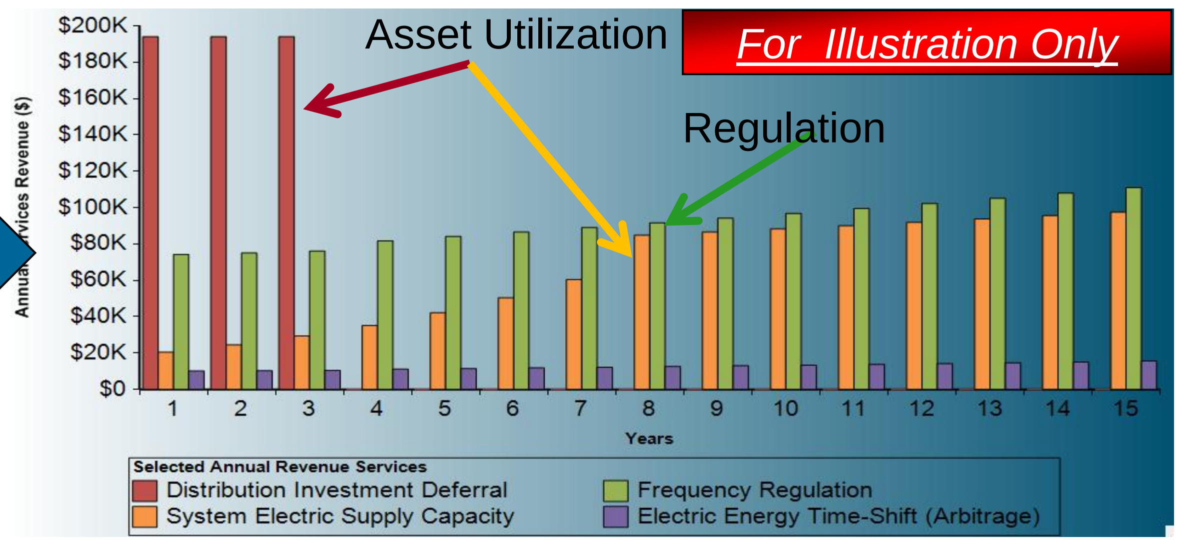
Storage value lies where it has a strong competitive advantage vs. conventional assets

- Use charging and discharging to simultaneously address both under (off-peak) and over-utilization (peak) of grid assets (T&D deferral & System capacity)
- Create value for storage charging, speed, and accuracy (Regulation)

Example of Distribution Energy Storage Annual Revenue by Service



- Value for energy time-shift (arbitrage) is comparatively low

Today's Proposed Agenda

- Introduction to EPRI
- Background
- Analytical Process
- **Discussion Break**
- Model
- Input Discussion Preface
- Performed Use Case Inputs and Results
  - #1: Bulk Storage (Peaker Substitution)
  - #2: Ancillary Services (Regulation) - only
- **Discussion Break / Lunch**
- Performed Use Case Inputs and Results
  - #3: Distributed Storage sited at Utility Substation
- Conclusions & Next Steps
- **Discussion**

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EPRI Introduction

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The Electric Power Research Institute (EPRI)

- Independent, non-profit, **collaborative** research institute, with full spectrum industry coverage
  - *Nuclear*
  - *Generation*
  - *Power Delivery & Utilization*
  - *Environment & Renewables*
- Major offices in Palo Alto, CA; Charlotte, NC; and Knoxville, TN

Technically informing regulatory / policy-makers fits within EPRI's mission

EPRI Energy Storage Program Mission

- Facilitate the development and implementation of storage options for the grid.
  - Understanding storage technologies
  - Identifying and calculating the impacts and value of storage
  - Specification and testing of storage products
  - Implementation and deployment of storage systems

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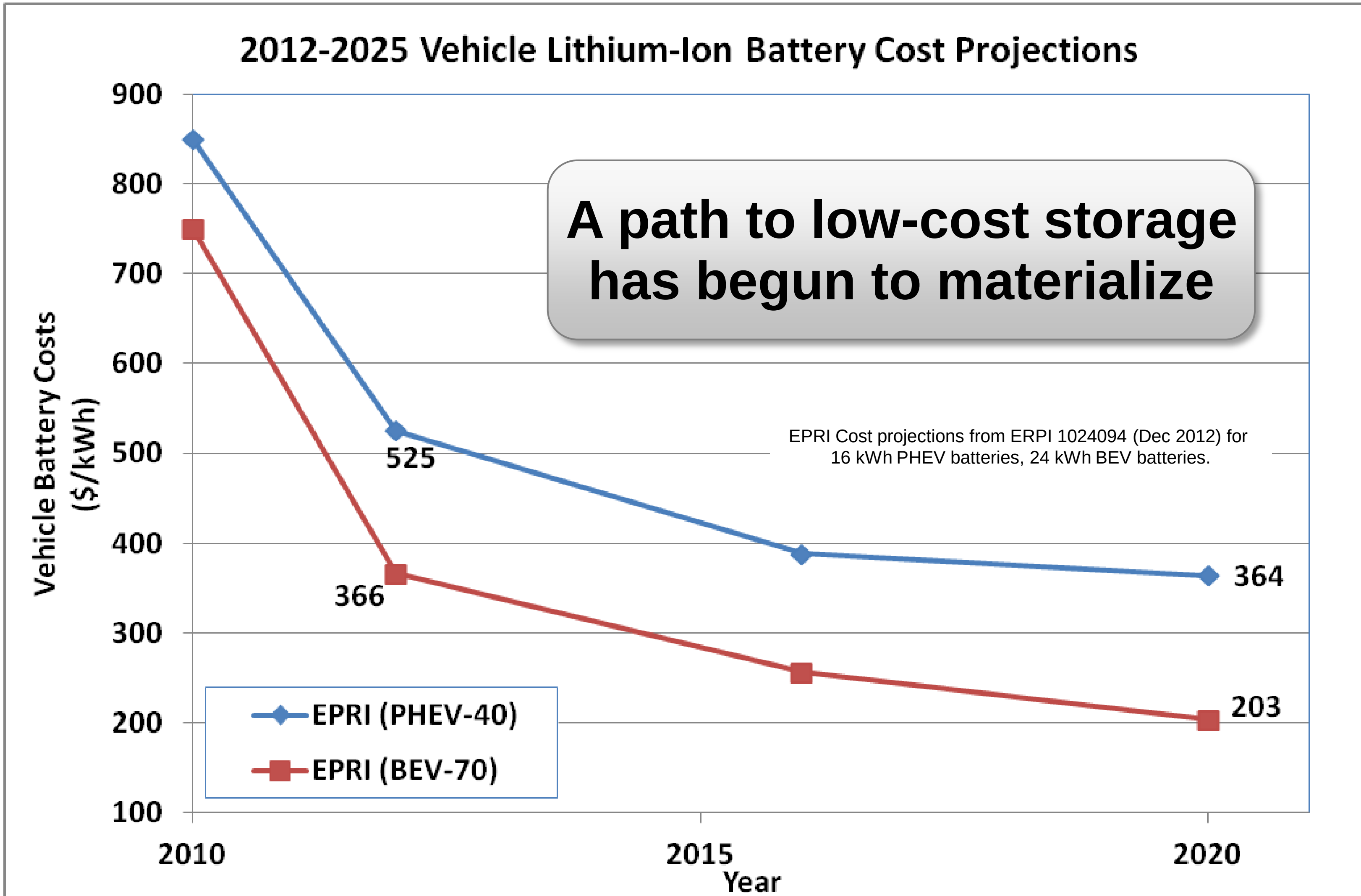
Storage costs are falling with manufacturing investment



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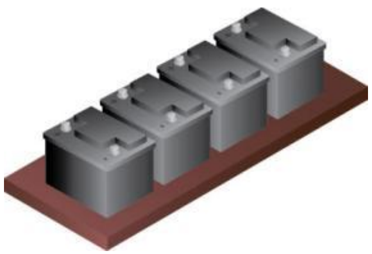
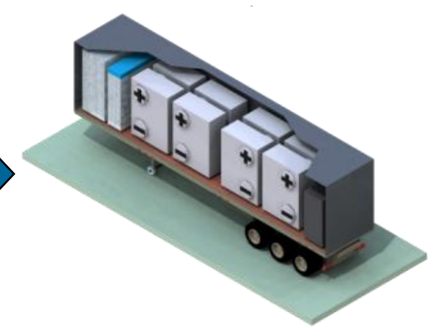
Creating a Complete Storage Product





Storage Technologies

- Define duty cycle and expectations for life and efficiency
- Characterize performance in different regimes

Power Conditioning System

- Define critical functions and performance levels
- Test capabilities to understand optimal performance

Product Integration

- Guidelines for integration of components to ensure proper performance
- Test and evaluate product as a whole

Acquiring complete, working systems has been the most challenging part of energy storage efforts to date

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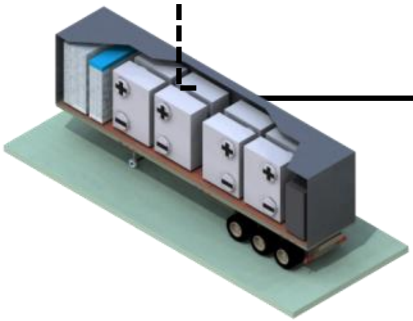
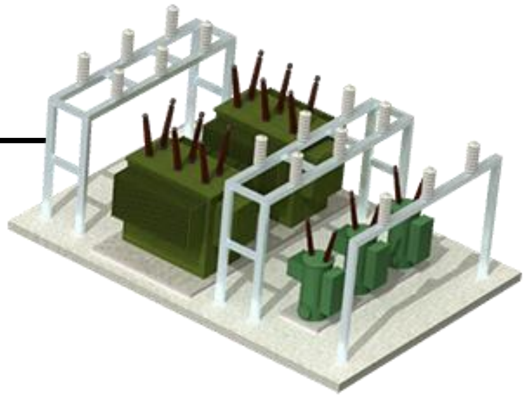
Grid Deployment and Integration





Field Deployment

- Installation, operations, and disposal best practices
- Siting and permitting issues
- Safety and emergency protocols

Grid Integration

- Physical interconnection and protection protocols
- Methods for understanding the effects on the distribution system

Control and Dispatch

- Communication and control protocol
- SGIP and cybersecurity
- Developing optimal dispatch algorithms

Interconnection of storage to the grid is still relatively poorly understood

Focus for Today's Presentation

- There are many areas of ongoing research to enable grid-ready energy storage

- **Today we are discussing one part: storage value analysis (under specific assumptions)**

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Background / Analytical Process

Overview of this Analytical Process

Timeframe	Phase	Description
2011/12	Model Development	**EPRI/E3** developed Energy Storage Valuation Tool (ESVT); Presented to CPUC Workshop Sept 2012.
Jan-Mar 2013	Scenario and Input Development	**CPUC technical staff** develop 50 desired model runs with inputs informed by CESA and 3 California IOU representatives.
Feb-Mar 2013	Analysis	**EPRI performs ~30 model runs.** Weekly check-in calls with CPUC and CESA to clarify inputs / progress; two presentations to CPUC, CESA, and IOU's in February and March; key additional sensitivities considered.
Mar-Jun 2013	Reporting	**EPRI** presentation of results at March 25 workshop with **CPUC provided inputs. EPRI** plans public report in approx. June 2013.

Overview of Process

Timeline	Process	Responsible Party
2011/12	Model Development	EPRI (w/ E3)
Jan-Mar 2013	Scenario and Input Development	CPUC (w/ CESA, PG&E, SCE, SDG&E)
Feb-Mar 2013	Analysis	EPRI
Mar-Jun 2013	Reporting	EPRI public report

Overview of EPRI Storage Cost-Effectiveness Methodology

Step 1a: Grid Problem / Solution Concepts Step 1b: Grid Service Requirements	Define quantifiable services storage can provide
Step 2: Feasible Use Cases	Understand "first-order" cost-effectiveness of quantifiable benefits
Step 3: Grid Impacts and Incidental Benefits	Understand storage impact on electric system/environment
Step 4: Energy Storage Business Cases	Investigate impact of policies, business models, etc.

EPRI Storage Cost-Effectiveness Methodology

Step 1a: Grid Problem / Solution Concepts

Step 1b: Grid Service Requirements

Define quantifiable services storage can provide

Step 2: Feasible Use Cases

Understand "first-order" cost-effectiveness of quantifiable benefits

Step 3: Grid Impacts and Incidental Benefits

Understand storage impact on electric system/environment

Step 4: Energy Storage Business Cases

Investigate impact of policies, business models, etc.

Not Included in Today's Analysis

EPRI Storage Cost-Effectiveness Methodology

Step 1a: Grid Problem / Solution Concepts

Step 1b: Grid Service Requirements

Define quantifiable services storage can provide

Step 2: Feasible Use Cases

Focus of this Analysis

Understand “first-order” cost-effectiveness of quantifiable benefits

Step 3: Grid Impacts and Incidental Benefits

Understand storage impact on electric system/environment

Not Included in Today’s Analysis

Step 4: Energy Storage Business Cases

Investigate impact of policies, business models, etc.

Overview of Step 2: Feasible Use Cases

- **Simulate energy storage use case operation** to address multiple grid services with quantifiable technical requirements and benefits
  - Prioritize serving long-term commitments (e.g. multi-year asset deferral over a day-ahead market opportunity)
  - Constrain operation by storage technical limitations
  - Co-optimize dispatch in the markets to maximize benefits
- **Total Resource Cost (TRC) test approach** – focus on aggregate ("stacked") value, ignore stakeholders & transaction costs
  - Ignore bulk system and environmental impacts
  - Ignore policy incentives and monetization restrictions

Understand which use case assumptions (technology, site, etc.) may make storage cost-effective, and which inputs are important.

CPUC Use Cases

Use Cases	Categories
Transmission-Connected Energy Storage	Bulk Storage System
	Ancillary Services
	On-Site Generation Storage
	On-Site Variable Energy Resource Storage
Distribution-Level Energy Storage	Distributed Peaker
	Distributed Storage Sited at Utility Substation
	Community Energy Storage
Demand-Side (Customer-Sited) Energy Storage	Customer Bill Management
	Customer Bill Management w/ Market Participation
	Behind the Meter Utility Controlled
	Permanent Load Shifting
	EV Charging

CPUC Use Cases Investigated in the Analysis

Use Cases	Categories
Transmission-Connected Energy Storage	Bulk Storage System (aka Peaker Subsitution)
	Ancillary Services
	On-Site Generation Storage
	On-Site Variable Energy Resource Storage
Distribution-Level Energy Storage	Distributed Peaker
	Distributed Storage Sited at Utility Substation
	Community Energy Storage
Demand-Side (Customer-Sited) Energy Storage	Customer Bill Management
	Customer Bill Management w/ Market Participation
	Behind the Meter Utility Controlled
	Permanent Load Shifting
	EV Charging

Focus limited due to project resource constraints

Use Cases Defined by Quantifiable Grid Services Addressed

Category	Quantifiable Grid Services	CPUC Use Cases Incl. in Analysis		
		Bulk-"Peaker Sub"	Ancillary Services	Dist. Sub. Storage
Energy	Electric Supply Capacity	X		X
	Electric Energy Time-Shift	X		X
A/S	Frequency Regulation	X	X	X
	Spinning Reserve	X		X
	Non-Spinning Reserve	X		X
Transmission	Transmission Upgrade Deferral			
	Transmission Voltage Support			
Distribution	Distribution Upgrade Deferral			X
	Distribution Voltage Support			
Customer	Power Quality			
	Power Reliability			
	Retail Demand Charge Mgmt			
	Retail Energy Time-Shift			

Other services and benefits may exist –

but they may be indirect or difficult to quantify

Discussion Break

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Energy Storage Valuation Tool Model

What is the Energy Storage Valuation Tool (ESVT) ?

Transparent, user-friendly, CBA tool to assess and communicate energy storage cost-effectiveness in different use cases

- Customizable storage **project lifecycle financial analysis**
- Includes **pre-loaded defaults** for energy storage service requirements, prioritization, values, storage technologies
- **Simulates use case cost-effectiveness** with Total Resource Cost (TRC) approach (stacks benefits across stakeholders)
- **Multi-stakeholder** services/benefits: Generation, Transmission, Distribution, Customer
- **Transparent model** approach with Analytica™ software - model / input transparency through influence diagrams

What is the Energy Storage Valuation Tool (ESVT) ?

Transparent, user-friendly, CBA tool to assess and communicate energy storage cost-effectiveness in different use cases

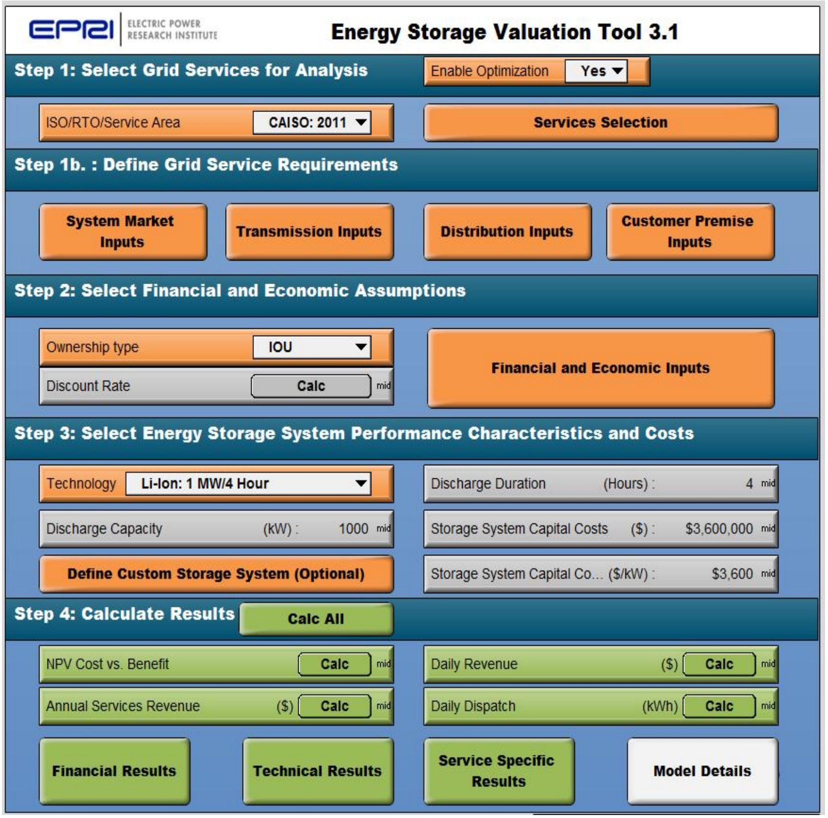

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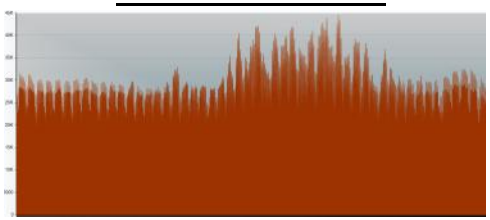
Illustration of ESVT Operation

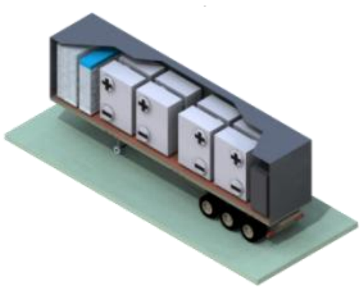
INPUTS

Prices / Loads



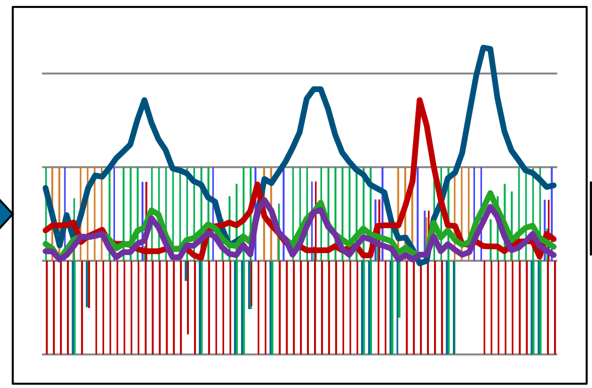
Financial Assumptions

Storage Cost / Performance



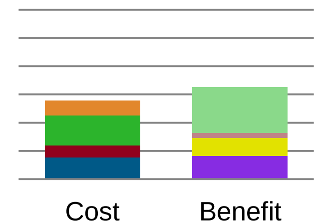
MODEL

Storage Priority / Bid / Dispatch

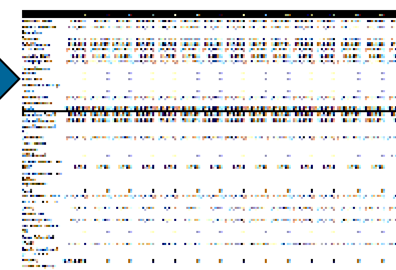


OUTPUTS

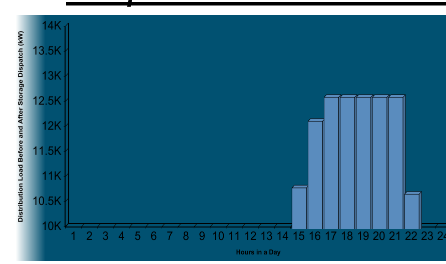
NPV Cost / Benefit



Detailed Financials



Dispatch Information



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Strengths and Current Limitations of ESVT

- Strengths
  - Quick to setup and run analyses – dozens of input parameters, not hundreds
  - Simulates storage optimal dispatch – provides insights into cost-effective use cases and relative importance of inputs
  - Designed specifically to incorporate storage cost / performance parameters
- Limitations
  - No system price or generators impacts measured – does not simulate the effects of different storage deployment levels
  - No consideration of environmental / GHG impacts

Discussion of Inputs to CPUC Analysis

Review of Analysis Inputs Process

		Responsible Party
2011/12	Model Development	EPRI (w/ E3)
Jan-Mar 2013	Scenario and Input Development	**CPUC (w/ CESA, PG&E, SCE, SDG&E)**
Feb-Mar 2013	Analysis	EPRI
Mar-Jun 2013	Reporting	EPRI public report

Review of Analysis Inputs Process

- December 2012 – Discussion of Use Cases for Initial Focus
  - Bulk – Peaker Substitution, A/S only
  - Distribution – Substation-sited
- Jan-Feb 2013 – CPUC request of 50 runs (prioritized)
- Jan-Mar 2013 – Weekly input clarification meetings with CPUC and 2 preliminary analysis results with stakeholder group
- March 2013 – Approximately 30 runs performed (time/budget constraints) with selected additional sensitivities

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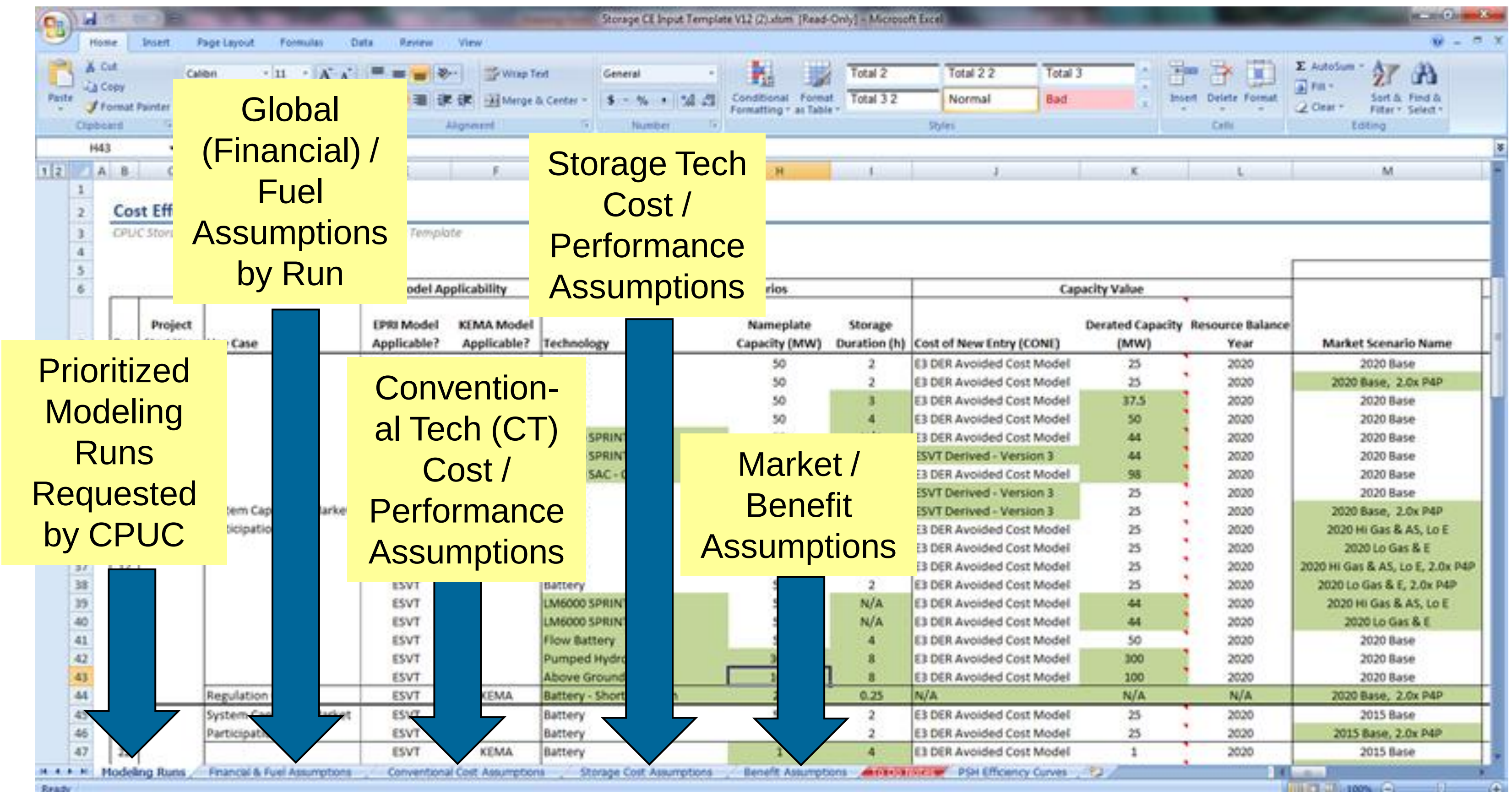
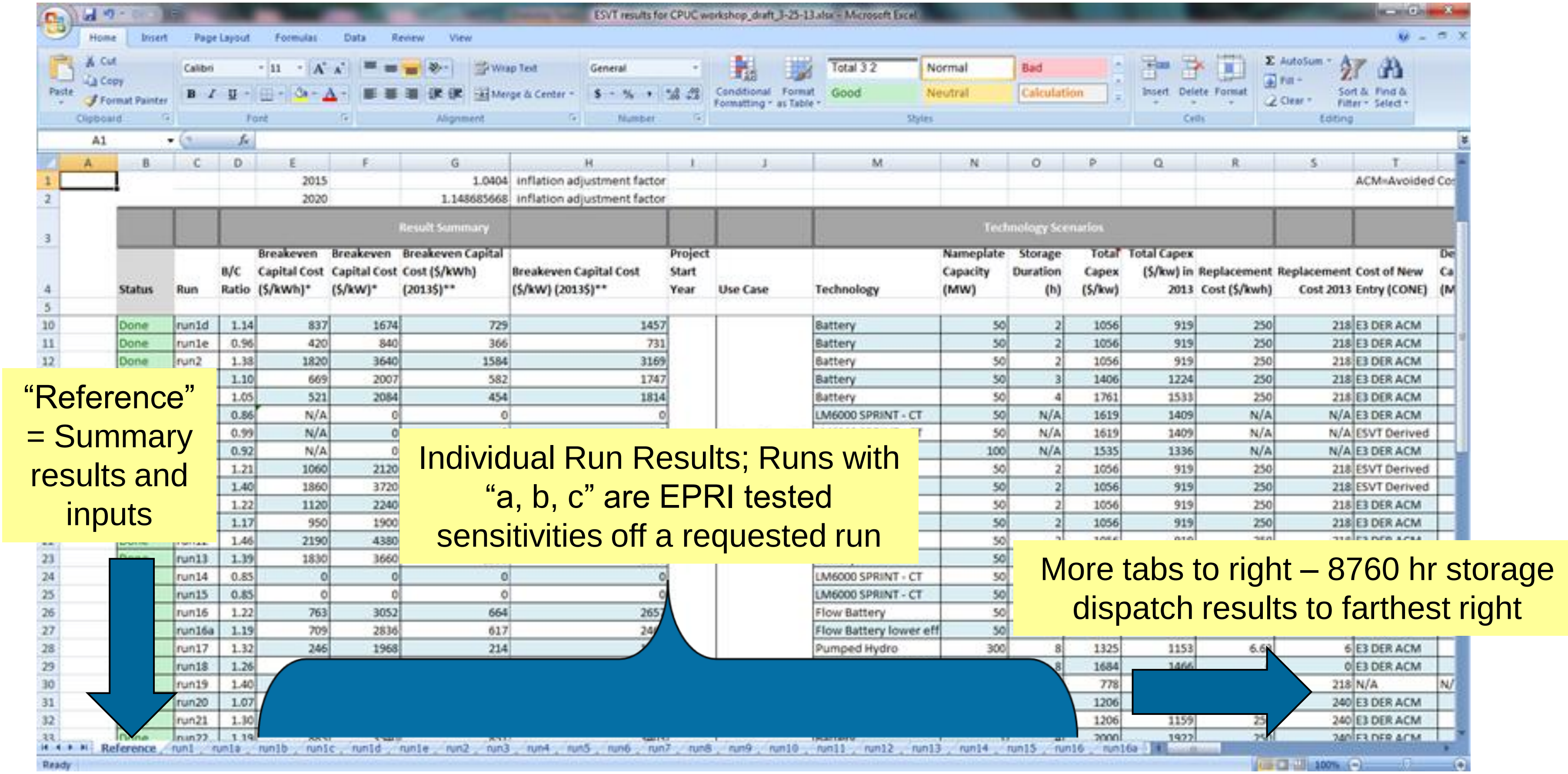
Overview of Input Worksheet provided by CPUC

- File: “Storage CE Input Template V12”



Overview of Results Worksheet provided by EPRI

- File: “ESVT Results for CPUC workshop_draft_3-25-13”



Use Case #1: Bulk Storage (Peaker Substitution) Inputs and Results

Reminder – 3 CPUC Use Cases

Category	Quantifiable Grid Services	CPUC Use Cases Incl. in Analysis		
		Bulk-"Peaker Sub"	Ancillary Services	Dist. Sub. Storage
Energy	Electric Supply Capacity	X		X
	Electric Energy Time-Shift	X		X
A/S	Frequency Regulation	X	X	X
	Spinning Reserve	X		X
	Non-Spinning Reserve	X		X
Transmission	Transmission Upgrade Deferral			
	Transmission Voltage Support			
Distribution	Distribution Upgrade Deferral			X
	Distribution Voltage Support			
Customer	Power Quality			
	Power Reliability			
	Retail Demand Charge Mgmt			
	Retail Energy Time-Shift			

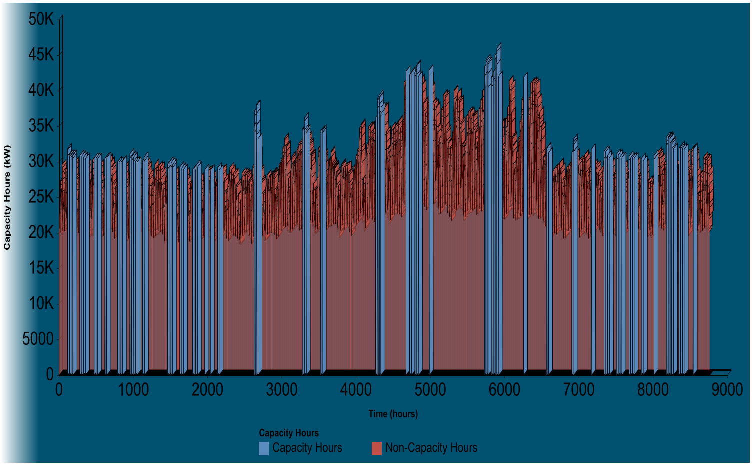
Bulk Storage Peaker Substitution

Category	Quantifiable Grid Services	CPUC Use Cases Incl. in Analysis
		Bulk-"Peaker Sub"
Energy	Electric Supply Capacity	X
	Electric Energy Time-Shift	X
A/S	Frequency Regulation	X
	Spinning Reserve	X
	Non-Spinning Reserve	X
Transmission	Transmission Upgrade Deferral	
	Transmission Voltage Support	
Distribution	Distribution Upgrade Deferral	
	Distribution Voltage Support	
Customer	Power Quality	
	Power Reliability	
	Retail Demand Charge Mgmt	
	Retail Energy Time-Shift	

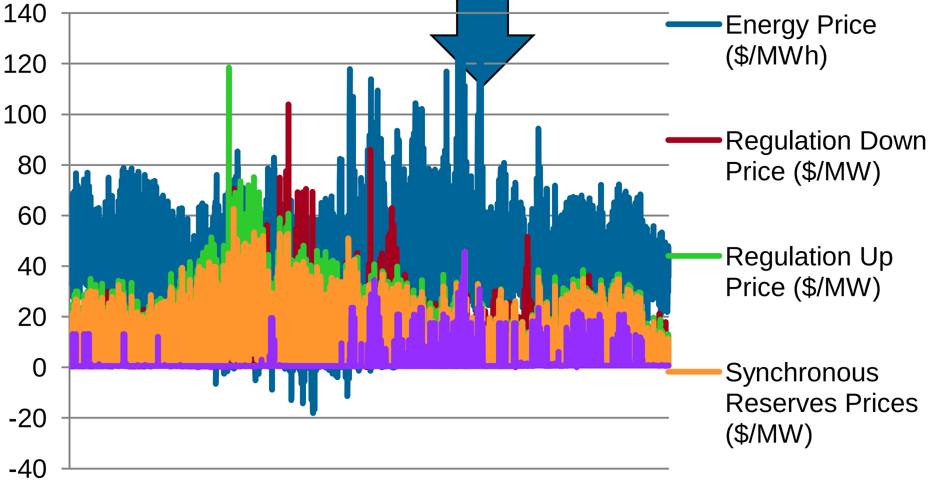
1. Electric Supply Capacity
2. Electric Energy Time Shift
3. Frequency Regulation
4. Spinning Reserve
5. Non-Spinning Reserve

Storage Dispatch Modeling Approach for Peaker Substitution Use Case

- Reserve top 20 CAISO load hours per month for providing energy to earn system capacity value

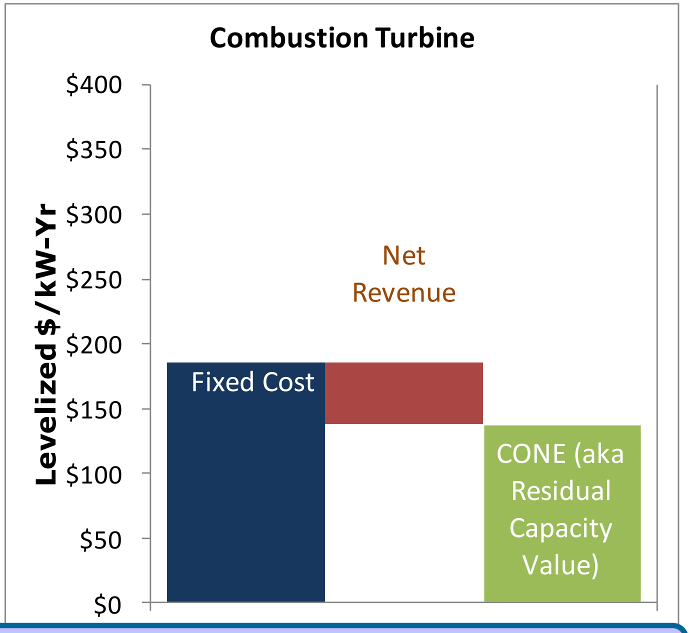


- Co-optimize for profitability between energy and ancillary services (reg up, reg down, spin, non-spin)



Before calculating storage cost effectiveness…

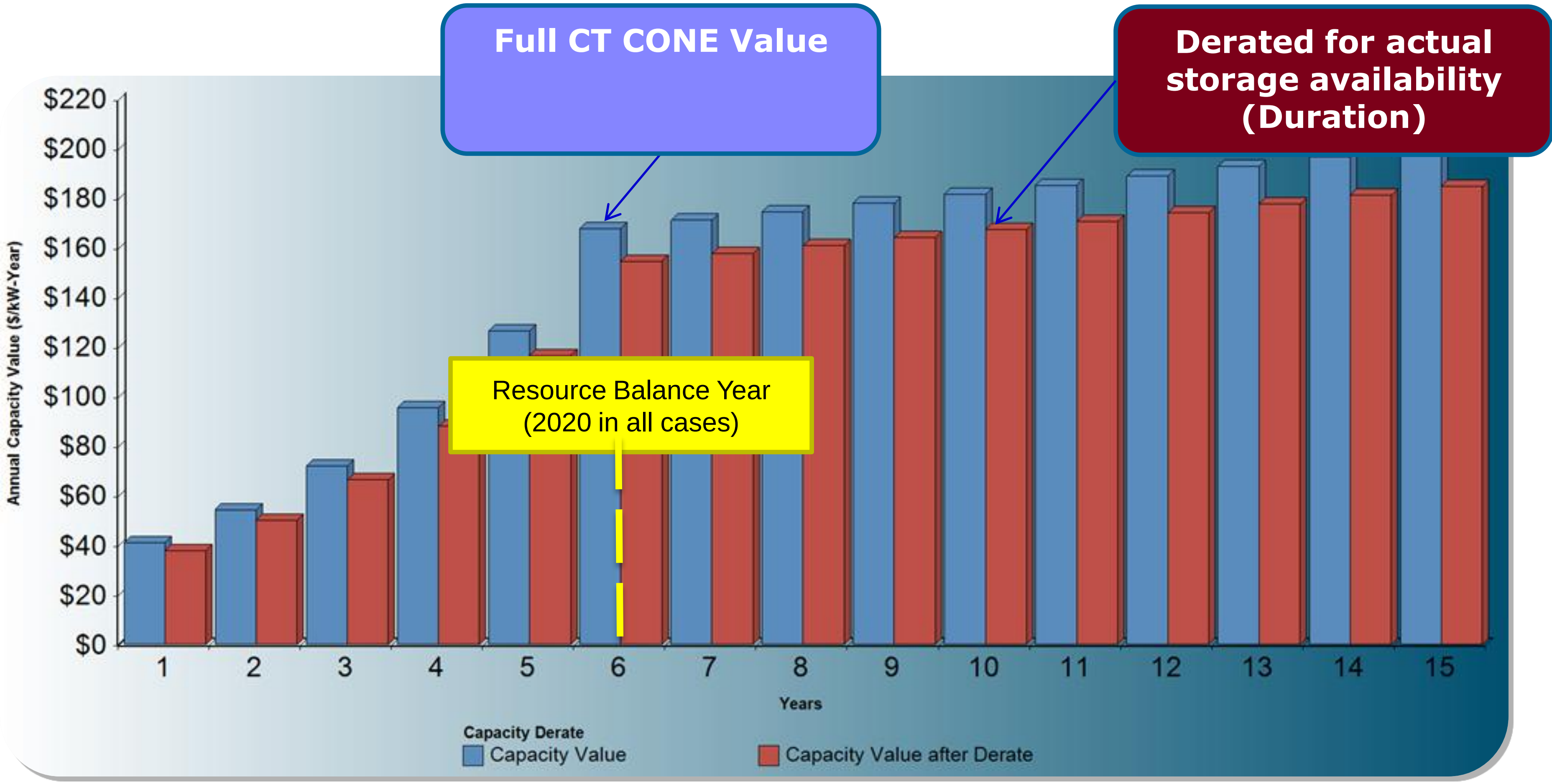
- We need a method for determining system capacity value
- System capacity value is determined by a metric called Cost of New Entry (CONE)
- CONE is the minimum required system capacity annual payment to build a new marginal combustion turbine(CT) – in California, LM6000 w/ SPRINT
- CONE was calculated two ways:
  - E3 DER Avoided Cost Calculator* (base)
  - ESVT Residual capacity value calc



CONE=Fixed Cost – Energy and AS Revenue

* http://www.ethree.com/documents/DERAvoidedCostModel_v3_9_2011_v4d.xlsm

System Capacity Revenue for Storage



CONE = $155/kW-yr (Derived from E3 DER avoided cost model)

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Deriving and Comparing CONE values for System Capacity Value

	E3 DER CONE Value	ESVT-Derived CONE
CONE Value (Residual Capacity Value)	$155/kW-yr	$203/kW-yr

Base Case Inputs

Year 2020

50MW

CapEx = $1619/kW

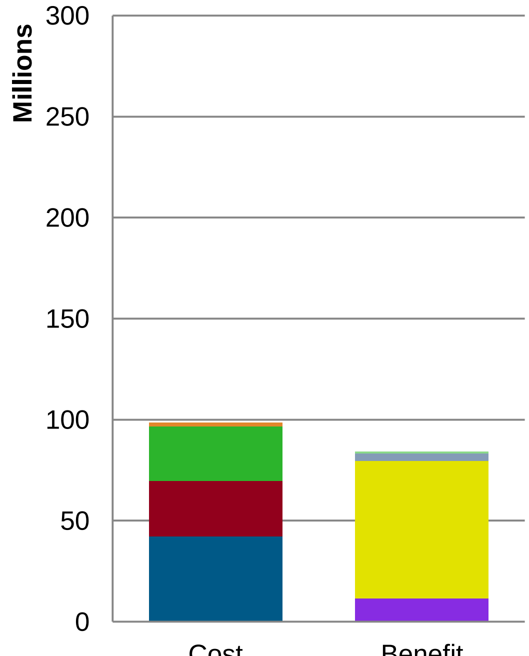
11.5% discount rate

Full Load Heat Rate = 9856 BTU/kWh

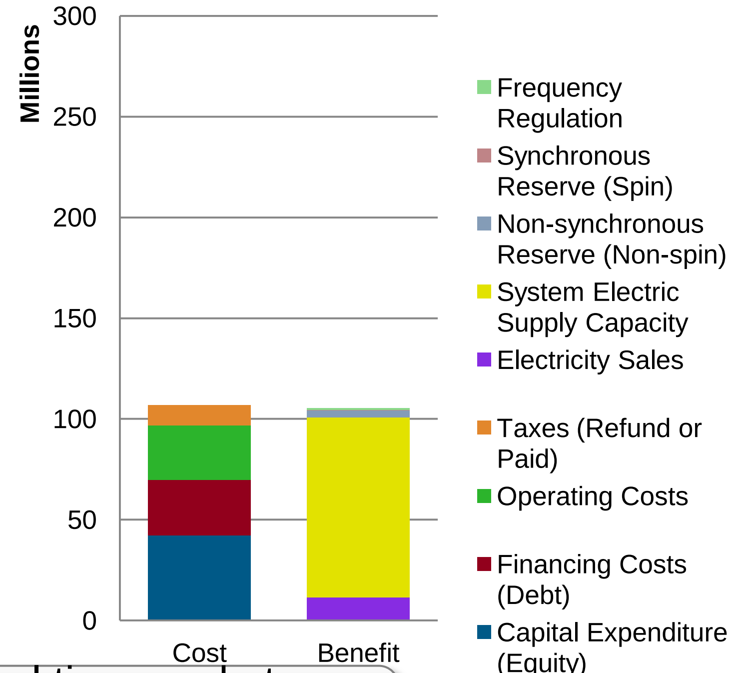
Heat rate curve in spreadsheet

Energy & A/S prices escalated 3%/yr from CAISO 2011

CT with E3 DER derived CONE (base)



CT ESVT Derived CONE



ESVT does not currently simulate CT participation in real time market, so ESVT CONE is likely somewhat inflated.

Bulk – Peaker Substitution Use Case Base Case Assumptions Provided by CPUC

- Key Global and System / Market Assumptions

Category	Input	2020	2015
Global	Financial Model	IPP	IPP
	Discount Rate	11.47%	11.47%
	Inflation Rate	2%	2%
	Fed Taxes	35%	35%
	State Taxes	8.84%	8.84%
System / Market	Base Year Reference	CAISO 2011	CAISO 2011
	Real Fuel Escalation Rate	2%	2%
	Energy & A/S Escalation Rate	3%	3%
	Yr 1 capacity value ($/kW-yr)	$155	$72
	CONE value ($/kW-yr)	$155	$155
	Resource Balance Year	2020	2020
	Mean Energy Price ($/MWh)	39.96	34.47
	Mean Reg Up Price ($/MW-hr)	12.01	10.36
	Mean Reg Down price ($/MW-hr)	9.04	7.80
	Mean Spin price ($/MW-hr)	9.43	8.13
	Mean Non-Spin price ($/MW-hr)	1.28	1.11

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Bulk – Peaker Substitution Base Case Assumptions Provided by CPUC

- Key technology cost / performance assumptions – storage and conventional (CT)

Category	Input	2020					2015	
		Battery*	Flow Battery	PHS	AG CAES	CT**	Battery	Flow Battery
Technology Cost / Performance	Nameplate Capacity (MW)	50	50	300	100	50	50	50
	Nameplate Duration (hr)	2	4	8	8	-	2	4
	Capital Cost ($/kWh) -Start Yr Nominal	528	443	166	211	-	603	775
	Capital Cost ($/kW) - Start Yr Nominal	1056	1772	1325	1684	1619	1206	3100
	Project Life (yr)	20	20	100	35	20	20	17
	Roundtrip Efficiency	83%	75%	82.50%	-	-	83%	70%
	Variable O&M ($/kWh)	0.00025	0.00025	0.001	0.003	0.004	0.00025	0.00025
	Fixed O&M ($/kW-yr)	15	15	7.5	5	17.4	15	15
	Major Replacement Frequency	1	0	-	-	-	1	0
	Major Replacement Cost ($/kWh)	250	-	-	-	-	250	-
	MACRS Depreciation Term (yr)	7	7	7	7	7	7	7
	Energy Charge Ratio (CAES)	-	-	-	0.7	-	-	-
	Full Capacity Heat Rate (CAES/CT)	-			3810	9387	-	-
	Heat Rate Curve (CAES/CT)	-	-	-	see wkst	see wkst	-	-
	Turbine Efficiency Curve (PHS)	-	-	see wkst	-	-	-	-
	Pump Efficiency (PHS)	-	-	see wkst	-	-	-	-

* Battery based loosely on Li-ion is most common base case

**CT based on LM6000 w/ SPRINT technology

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Run 1: Peaker Substitution Result for Base Case with CPUC Inputs

- **Benefit/Cost Ratio** = 1.17
- **Breakeven Capital Cost:** $831/kWh ($1662/kW) in 2013 inflation adjusted dollars

<u>Base Case Inputs</u>

Year 2020

50MW, 2hr (battery)

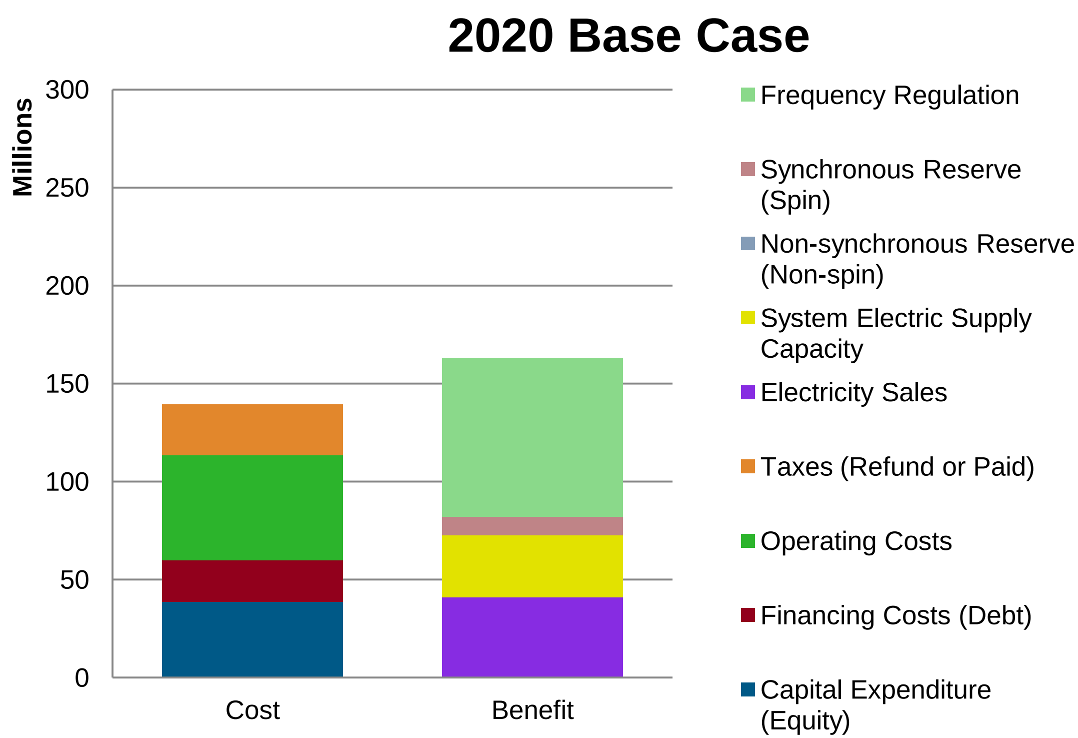
CapEx = $1056/kW, $528/kWh

1 Batt Replacement @ $250/kWh

11.5% discount rate

83% RT Efficiency

Energy & A/S prices escalated 3%/yr from CAISO 2011



Sensitivity to Regulation Service Value (1 of 2)
1X Regulation Price vs. 2X Price

	Base Case	Base Case + 2x Reg
Breakeven Capital Cost in 2013 dollars	$831/kWh ($1662/kW)	$1584 /kWh ($3168/kW)

<u>Base Case Inputs</u>

Year 2020

50MW, 2hr (battery)

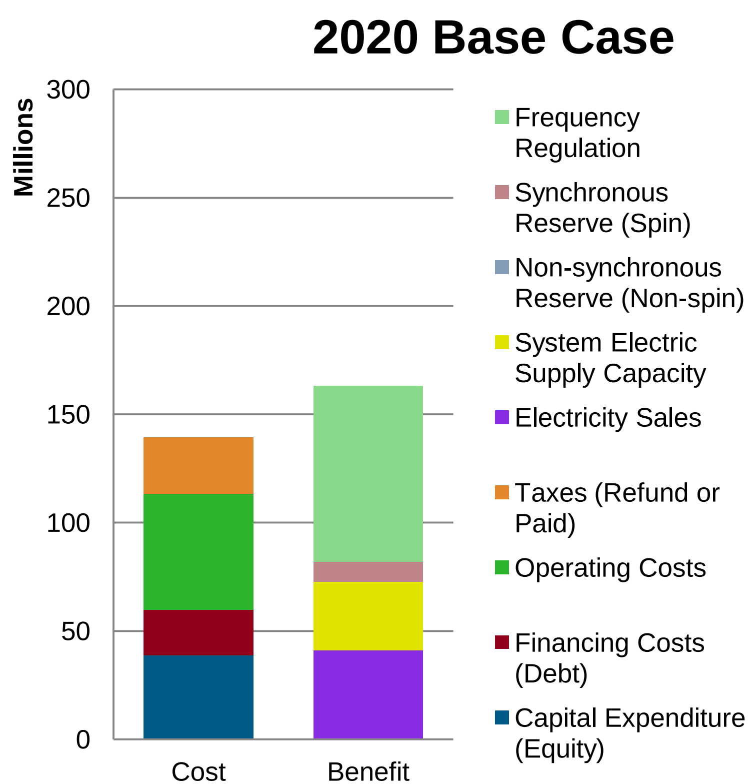
CapEx = $1056/kW, $528/kWh

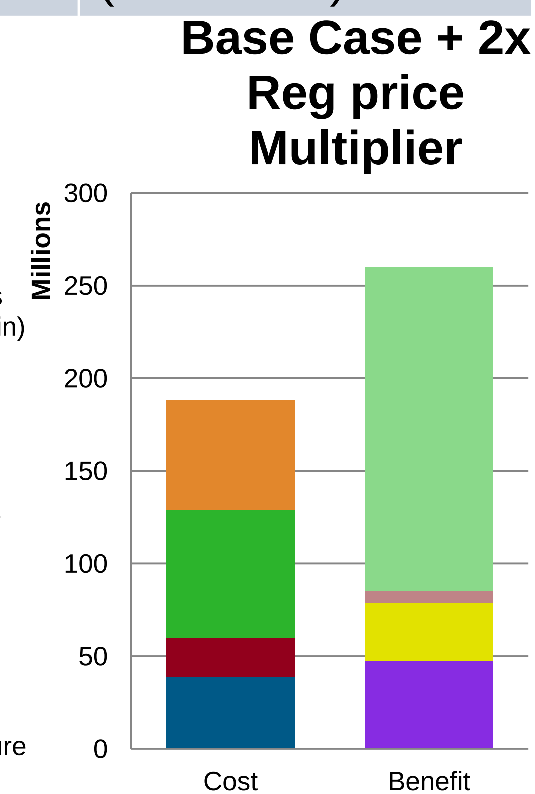
1 Batt Replacement @ $250/kWh

11.5% discount rate

83% RT Efficiency

Energy & A/S prices escalated 3%/yr from CAISO 2011





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Sensitivity to Regulation Service Value (2 of 2) Base Regulation Value vs. No Regulation Value

	Base Case	Base Case w/o Regulation
Breakeven Capital Cost in 2013 dollars	\$831 /kWh (\$1662/kW)	\$423 /kWh (\$846/kW)

Base Case Inputs

Year 2020

50MW, 2hr (battery)

CapEx = \$1056/kW, \$528/kWh

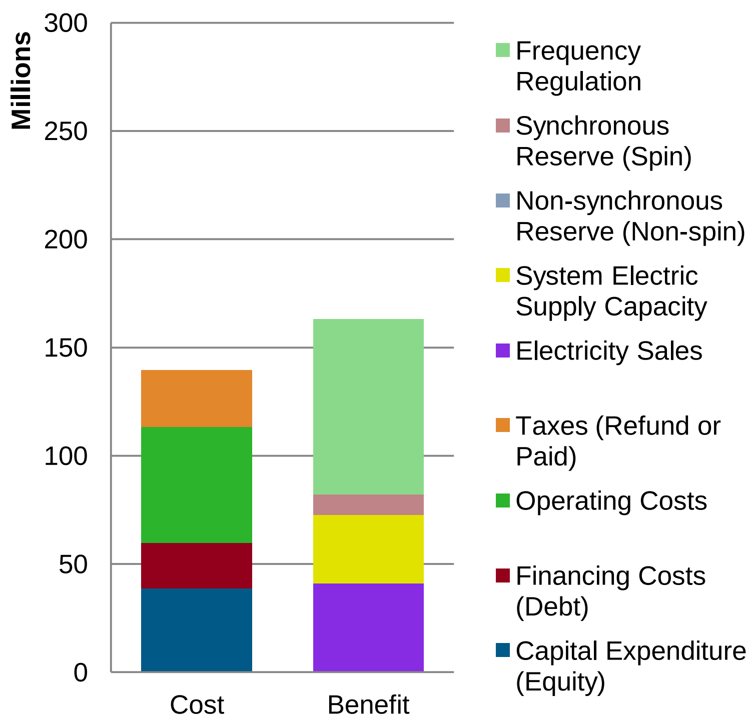
1 Batt Replacement @ \$250/kWh

11.5% discount rate

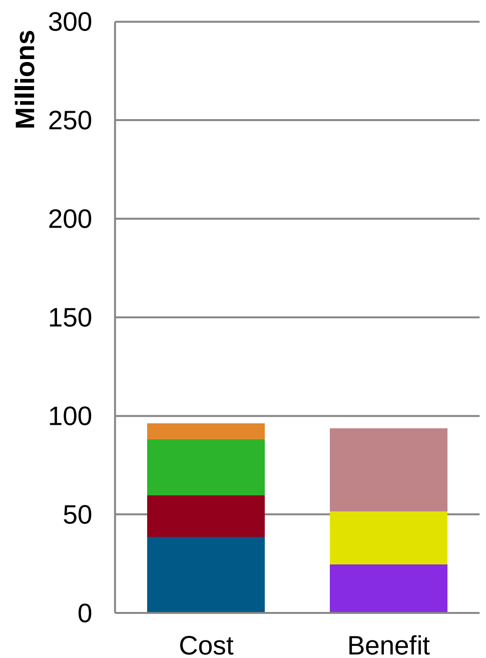
83% RT Efficiency

Energy & A/S prices escalated 3%/yr from CAISO 2011

2020 Base Case

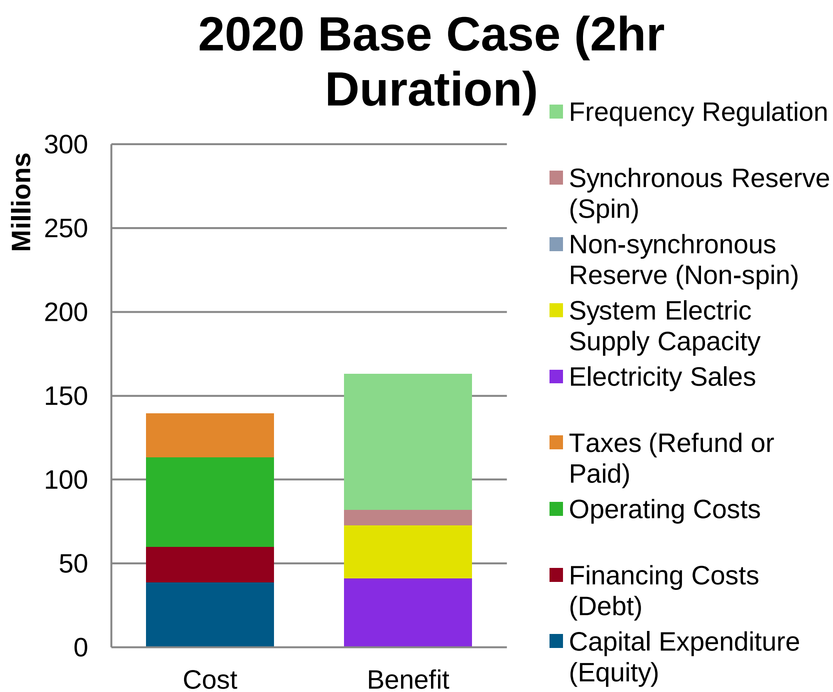


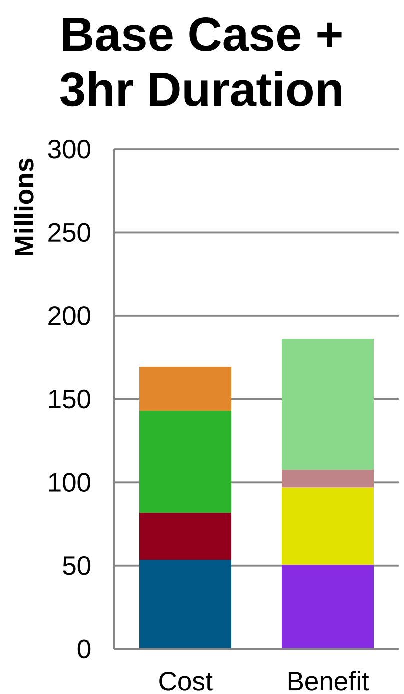
Base Case w/o Regulation

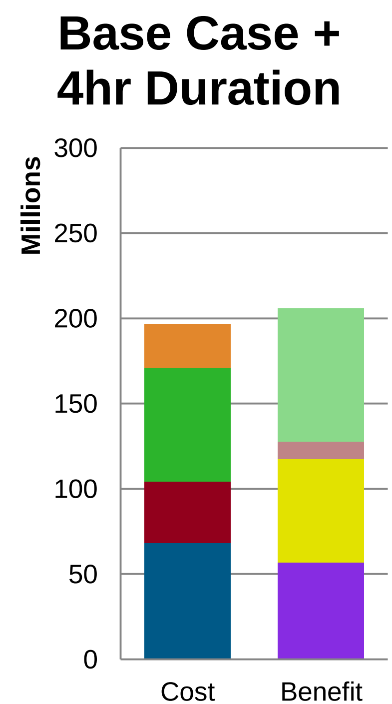


Sensitivity to Storage Duration Configuration
Base Case (2hr) vs. 3hr vs. 4hr

	Base Case	Duration 3hr	Duration 4hr
Breakeven Capital Cost in 2013 dollars	$831 /kWh ($1662/kW)	$582 /kWh ($1746/kW)	$454 /kWh ($1816/kW)







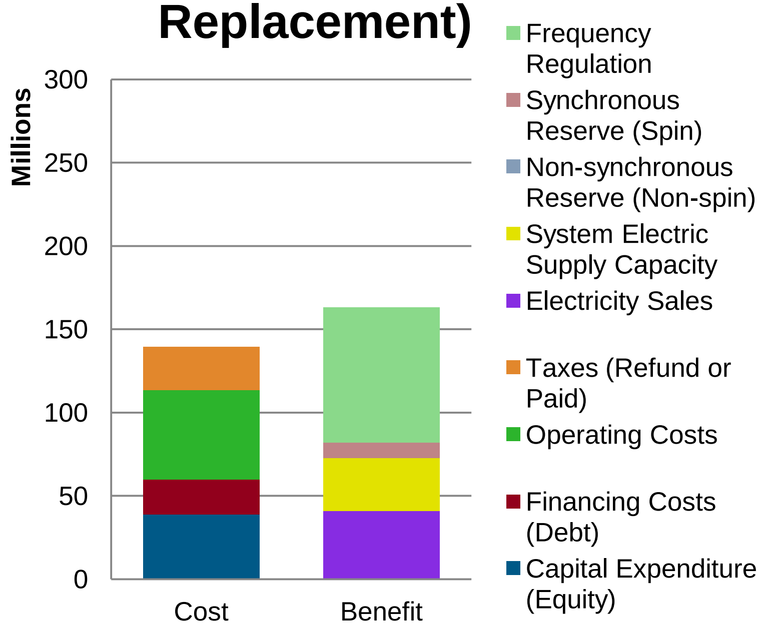
Base Case Inputs

Year 2020; 50MW, 2hr (battery); CapEx = $1056/kW, $528/kWh; 1 Batt Replacement @ $250/kWh; 11.5% discount rate; 83% RT Efficiency; Energy & A/S prices escalated 3%/yr from CAISO 2011

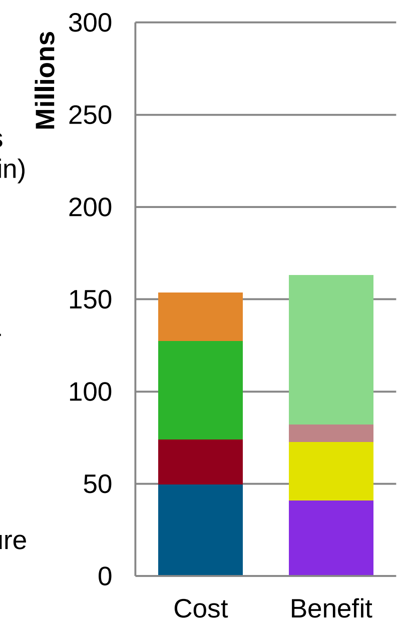
Sensitivity to Battery Replacement Frequency*

No. of Replacements	Base Case (1X)	Base + 2X replace	Base + 3X replace
Breakeven Capital Cost in 2013 dollar	$831 /kWh ($1662/kW)	$582 /kWh ($1164/kW)	$454 /kWh ($908/kW)

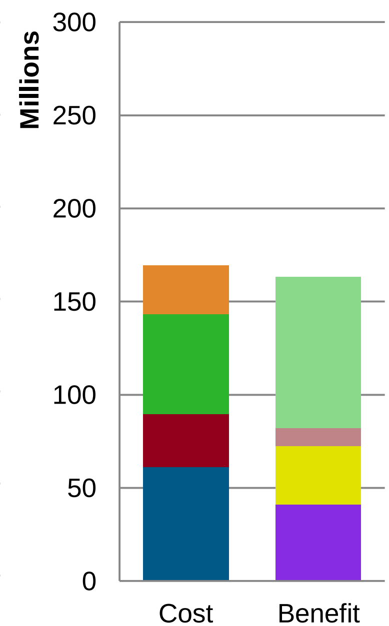
2020 Base Case (1 Replacement)



Base Case + 2 Replacements



Base Case + 3 Replacements



Base Case Inputs

Year 2020; 50MW, 2hr (battery); CapEx = $1056/kW, $528/kWh; Batt Replacements @ $250/kWh; Battery replacements equally spaced over 20 yr life; 11.5% discount rate; 83% RT Efficiency; Energy & A/S prices escalated 3%/yr from CAISO 2011

Sensitivity to Project Start Year: 2020 vs. 2015

	Base Case (2020 start)	Base Case (2015 start)
Breakeven Capital Cost in 2013 dollars	$831/kWh ($1662/kW)	$749/kWh ($1498/kW)

Base Case Inputs

Year 2020

50MW, 2hr (battery)

CapEx = $1056/kW, $528/kWh

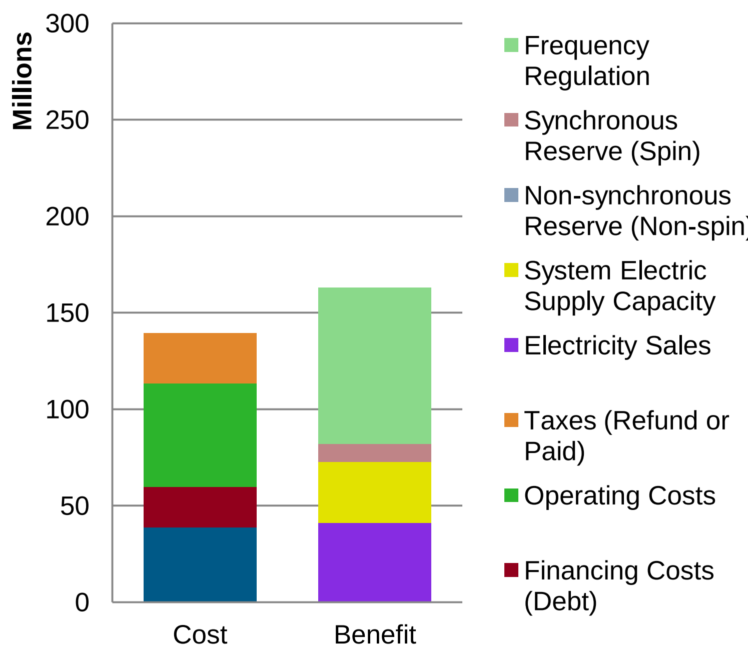
1 Batt Replacement @ $250/kWh

11.5% discount rate

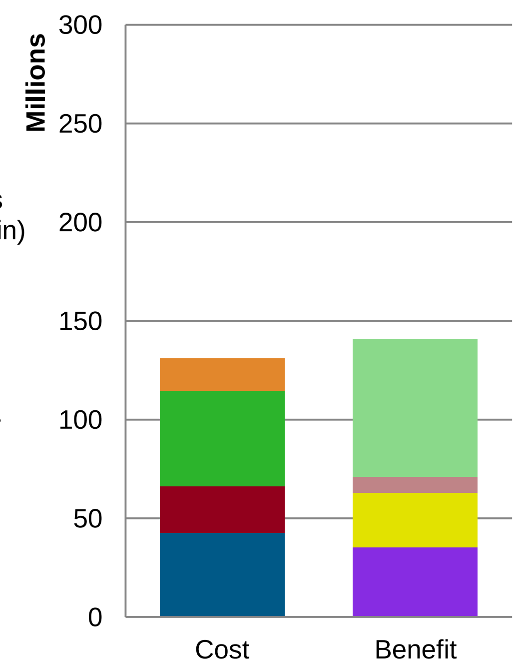
83% RT Efficiency

Energy & A/S prices escalated 3%/yr from CAISO 2011

2020 Base Case



Base Case w/ 2015 start



Other Technology Comparison (Flow Battery, CAES, Pumped Hydro)

	Flow Battery	Pumped Hydro	Abv Ground CAES
Breakeven Capital Cost in 2013 dollars	$664/kWh ($2657/kW)	$214/kWh ($1713/kW)	$224/kWh ($1790/kW)

Global Inputs

11.5% discount rate

Energy & A/S prices escalated 3%/yr from CAISO 2011

Flow Battery Inputs

50MW, 4hr (battery)

CapEx = $1772/kW

75% RT Efficiency

No battery replacements

PH Inputs

300MW, 8hr

$1325/kW, 100 yr project life

VO&M = $1.02/MWh, FO&M = $7.5/kW-yr

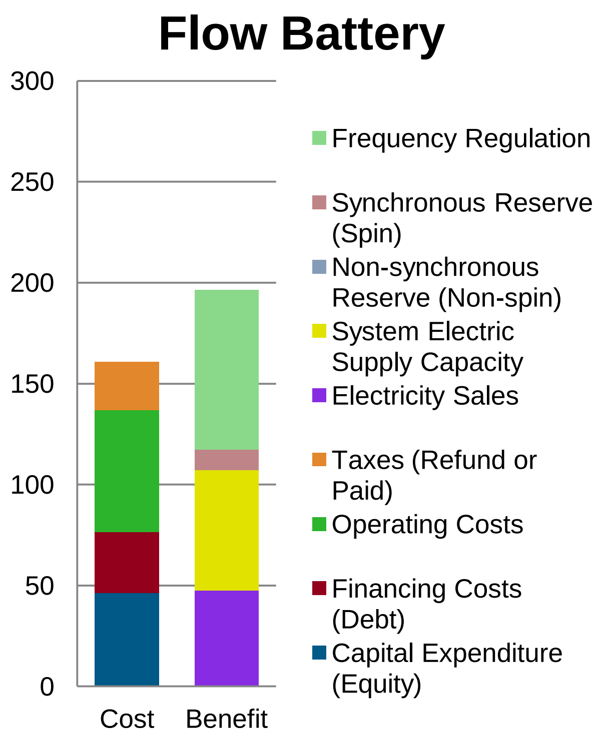
CAES Inputs

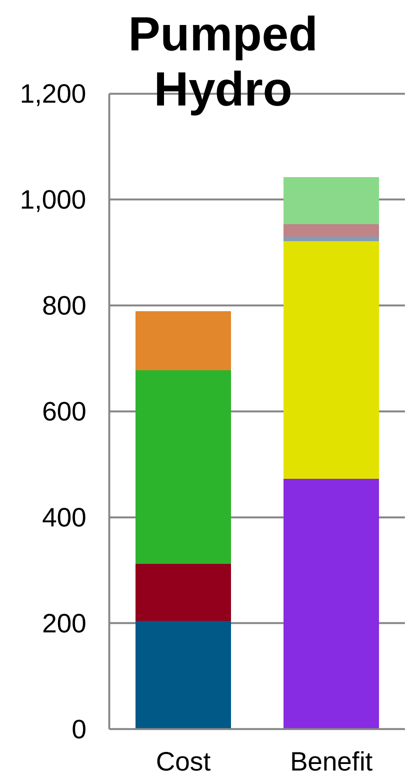
100MW, 8h

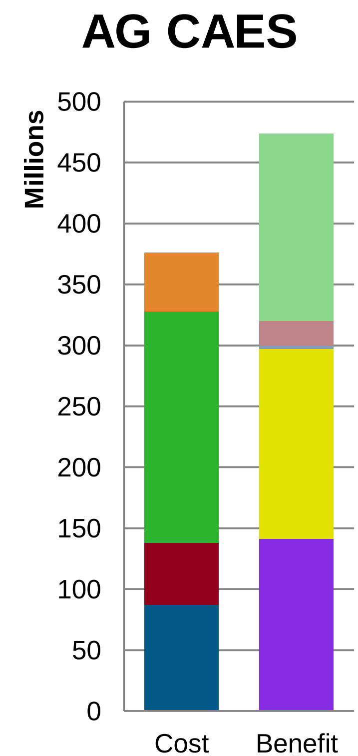
$1584/kW, 35 yr life

Energy charge ratio = 0.7

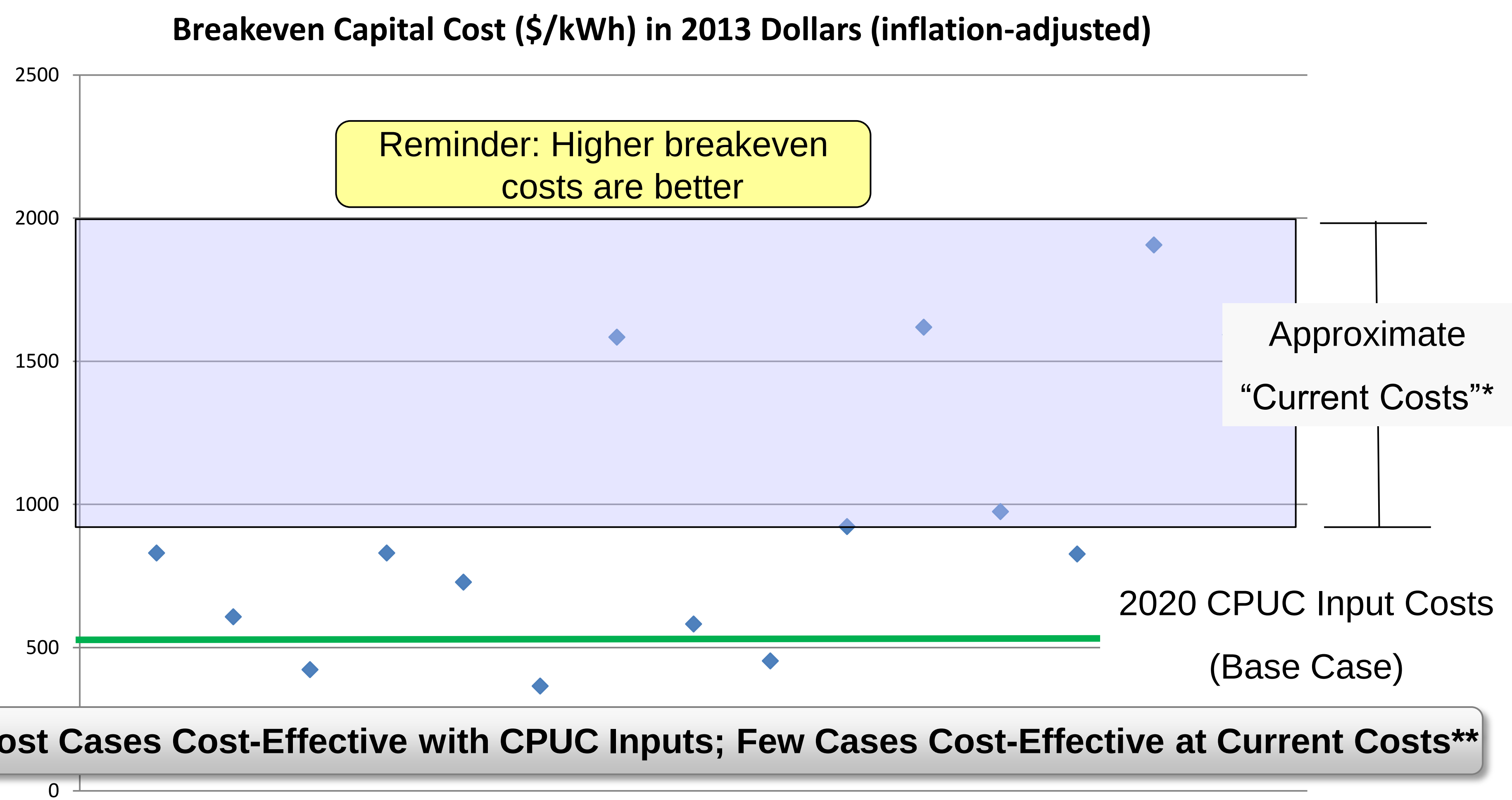
Full load heat rate = 3810







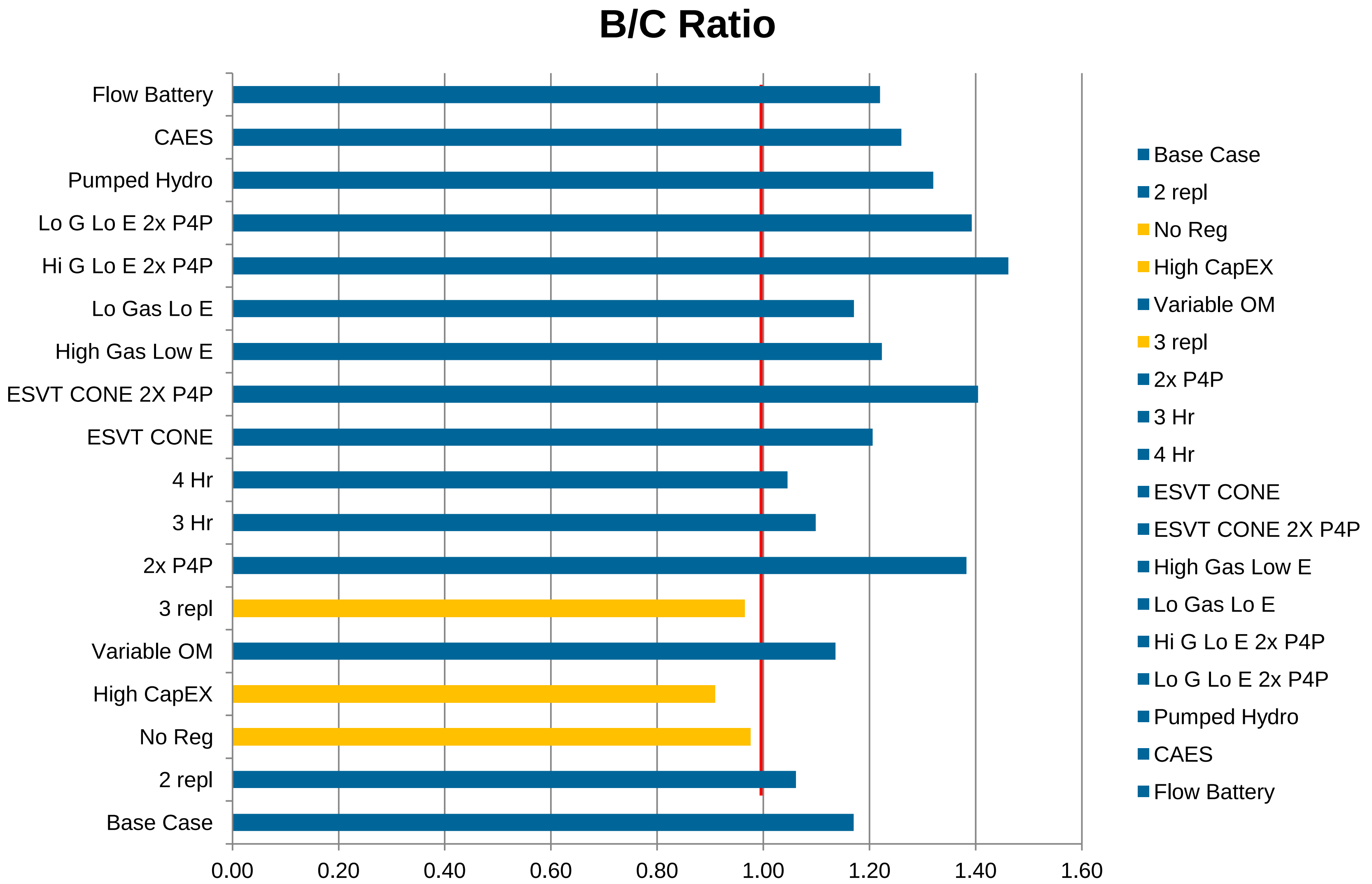
Overview of Bulk / Peaker Results in ESVT - Breakeven Capital Costs (CPUC Inputs)



* Based on 2011 EPRI Storage Cost Survey and other sources

** "Current costs" applicable to 2-4hr battery, not other technologies contained

Summary of B/C ratio results for Bulk Storage (Peaker Sub) – CPUC Inputs / Costs



Use Case #2: A/S (Regulation)–only Inputs & Results

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Reminder – 3 CPUC Use Cases

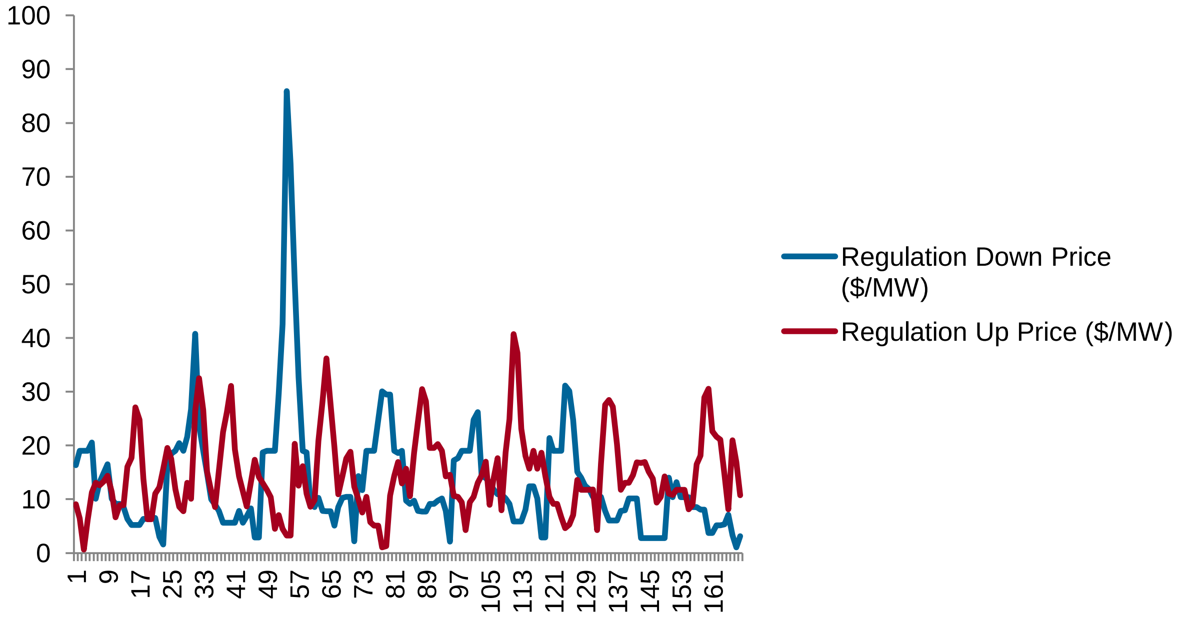
Category	Quantifiable Grid Services	CPUC Use Cases Incl. in Analysis		
		Bulk-"Peaker Sub"	Ancillary Services	Dist. Sub. Storage
Energy	Electric Supply Capacity	X		X
	Electric Energy Time-Shift	X		X
A/S	Frequency Regulation	X	X	X
	Spinning Reserve	X		X
	Non-Spinning Reserve	X		X
Transmission	Transmission Upgrade Deferral			
	Transmission Voltage Support			
Distribution	Distribution Upgrade Deferral			X
	Distribution Voltage Support			
Customer	Power Quality			
	Power Reliability			
	Retail Demand Charge Mgmt			
	Retail Energy Time-Shift			

A/S (Regulation)-Only

Category	Quantifiable Grid Services	CPUC Use Cases Incl. in Analysis		
			Ancillary Services	
Energy	Electric Supply Capacity			
	Electric Energy Time-Shift			
A/S	Frequency Regulation		X	1.Frequency Regulation
	Spinning Reserve			
	Non-Spinning Reserve			
Transmission	Transmission Upgrade Deferral			
	Transmission Voltage Support			
Distribution	Distribution Upgrade Deferral			
	Distribution Voltage Support			
Customer	Power Quality			
	Power Reliability			
	Retail Demand Charge Mgmt			
	Retail Energy Time-Shift			

Storage Dispatch Modeling Approach for Regulation Only Use Case

- Optimize for profitability between regulation up, regulation down, and no action; manage storage state-of-charge
- Account for associated charging / discharging costs and revenues



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A/S (Regulation)-only Base Case Assumptions Provided by CPUC (1 case)

- Key Global and System / Market Assumptions

Category	Input	2020
Global	Financial Model	IPP
	Discount Rate	11.47%
	Inflation Rate	2%
	Fed Taxes	35%
	State Taxes	8.84%
System / Market	Base Year Reference	CAISO 2011
	Real Fuel Escalation Rate	2%
	Energy & A/S Escalation Rate	3%
	Mean Energy Price ($/MWh)	39.96
	Mean Reg Up Price ($/MW-hr)	12.01
	Mean Reg Down Price ($/MW-hr)	9.04

A/S (Regulation)-only Base Case Assumptions Provided by CPUC (1 case)

- Key technology cost / performance assumptions

Category	Input	2020
		Battery
Technology Cost / Performance	Nameplate Capacity (MW)	20
	Nameplate Duration (hr)	0.25
	Capital Cost ($/kWh) -Start Yr Nominal	3112
	Capital Cost ($/kW) - Start Yr Nominal	778
	Project Life (yr)	20
	Roundtrip Efficiency	83%
	Variable O&M ($/kWh)	0.00025
	Fixed O&M ($/kW-yr)	15
	Major Replacement Frequency	1
	Major Replacement Cost ($/kWh)	250
	MACRS Depreciation Term (yr)	7

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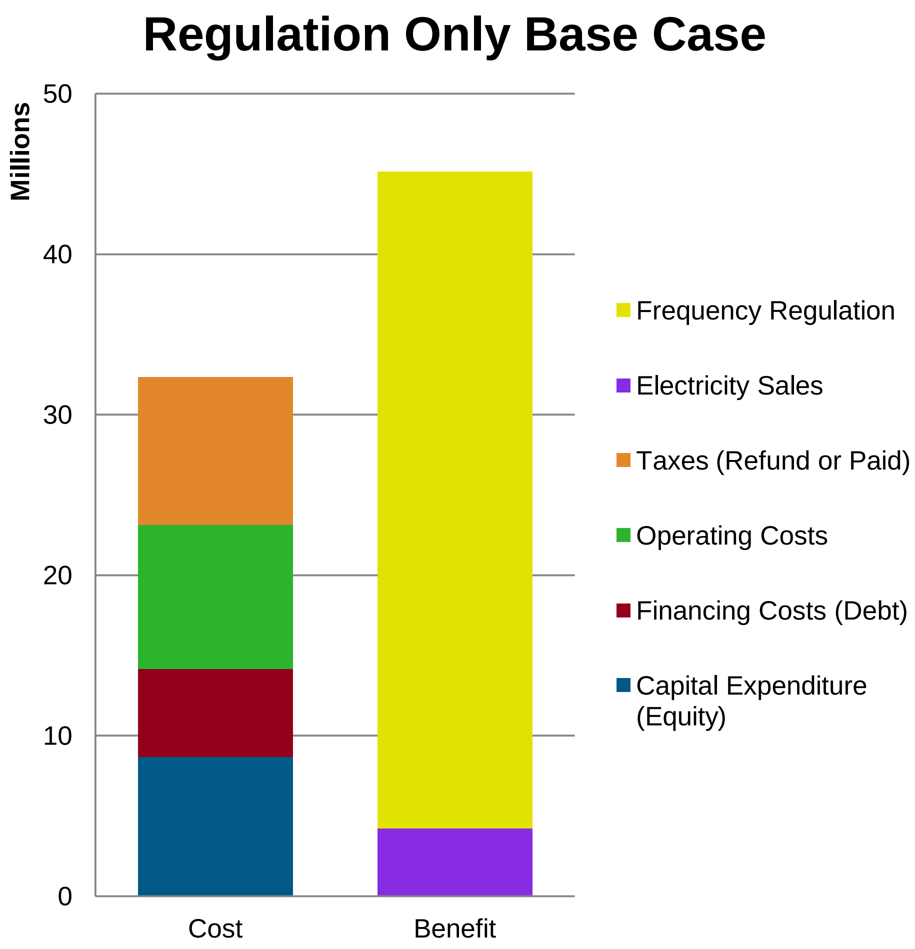
Regulation Only Result (2x Regulation Price Multiplier)



B/C Ratio	1.40
Breakeven Capital Cost in 2013 dollars	$1678/kW ($6712/kWh)

Discussion Break / Lunch

Use Case #3: Distribution Storage at Substation Inputs & Results

Reminder – 3 CPUC Use Cases

Category	Quantifiable Grid Services	CPUC Use Cases Incl. in Analysis		
		Bulk-"Peaker Sub"	Ancillary Services	Dist. Sub. Storage
Energy	Electric Supply Capacity	X		X
	Electric Energy Time-Shift	X		X
A/S	Frequency Regulation	X	X	X
	Spinning Reserve	X		X
	Non-Spinning Reserve	X		X
Transmission	Transmission Upgrade Deferral			
	Transmission Voltage Support			
Distribution	Distribution Upgrade Deferral			X
	Distribution Voltage Support			
Customer	Power Quality			
	Power Reliability			
	Retail Demand Charge Mgmt			
	Retail Energy Time-Shift			

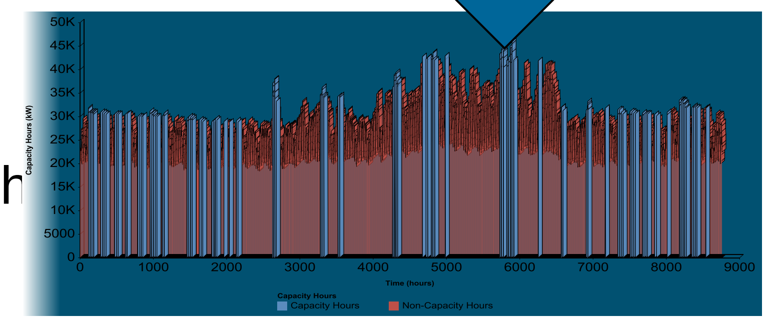
Distribution Storage at Substation

Category	Quantifiable Grid Services	CPUC Use Cases Incl. in Analysis	
			Dist. Sub. Storage
Energy	Electric Supply Capacity	1.Electric Supply Capacity 2.Electric Energy Time Shift 3.Frequency Regulation 4.Spinning Reserve 5.Non-Spinning Reserve 6. Distribution Upgrade Deferral	X
	Electric Energy Time-Shift		X
A/S	Frequency Regulation		X
	Spinning Reserve		X
	Non-Spinning Reserve		X
Transmission	Transmission Upgrade Deferral		
	Transmission Voltage Support		
Distribution	Distribution Upgrade Deferral		X
	Distribution Voltage Support		
Customer	Power Quality		
	Power Reliability		
	Retail Demand Charge Mgmt		
	Retail Energy Time-Shift		

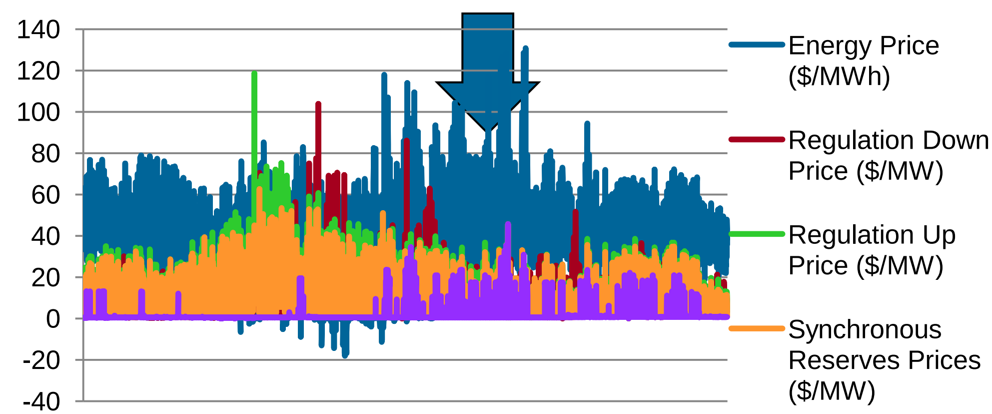
Storage Dispatch Modeling Approach for Distribution Storage at Substation Use Case

- Top priority: Peak shave annual peak distribution load to offset load growth and defer upgrade investment for years

- Second priority: Reserve Top 20 CAISO load hours per month for providing energy



- Co-optimize for profitability between energy and ancillary services (reg up, reg down, spin, non-spin)



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Distributed Storage at Substation Base Case Assumptions Provided by CPUC

- Key Global and System / Market Assumptions

Category	Input	2020	2015
Global	Financial Model	IPP	IPP
	Discount Rate	11.47%	11.47%
	Inflation Rate	2%	2%
	Fed Taxes	35%	35%
	State Taxes	8.84%	8.84%
System / Market	Base Year Reference	CAISO 2011	CAISO 2011
	Real Fuel Escalation Rate	2%	2%
	Energy & A/S Escalation Rate	3%	3%
	Cost of Distribution Upgrade ($/kW)	$309	$279
	Feeder Type	C&I	C&I
	Load Growth Rate	2%	2%
	Yr 1 capacity value ($/kW-yr)	$155	$72
	CONE value ($/kW-yr)	$155	$155
	Resource Balance Year	2020	2020
	Mean Energy Price ($/MWh)	39.96	34.47
	Mean Reg Up Price ($/MW-hr)	12.01	10.36
	Mean Reg Down Price ($/MW-hr)	9.04	7.80
	Mean Spin Price ($/MW-hr)	9.43	8.13
	Mean Non-Spin Price ($/MW-hr)	1.28	1.11

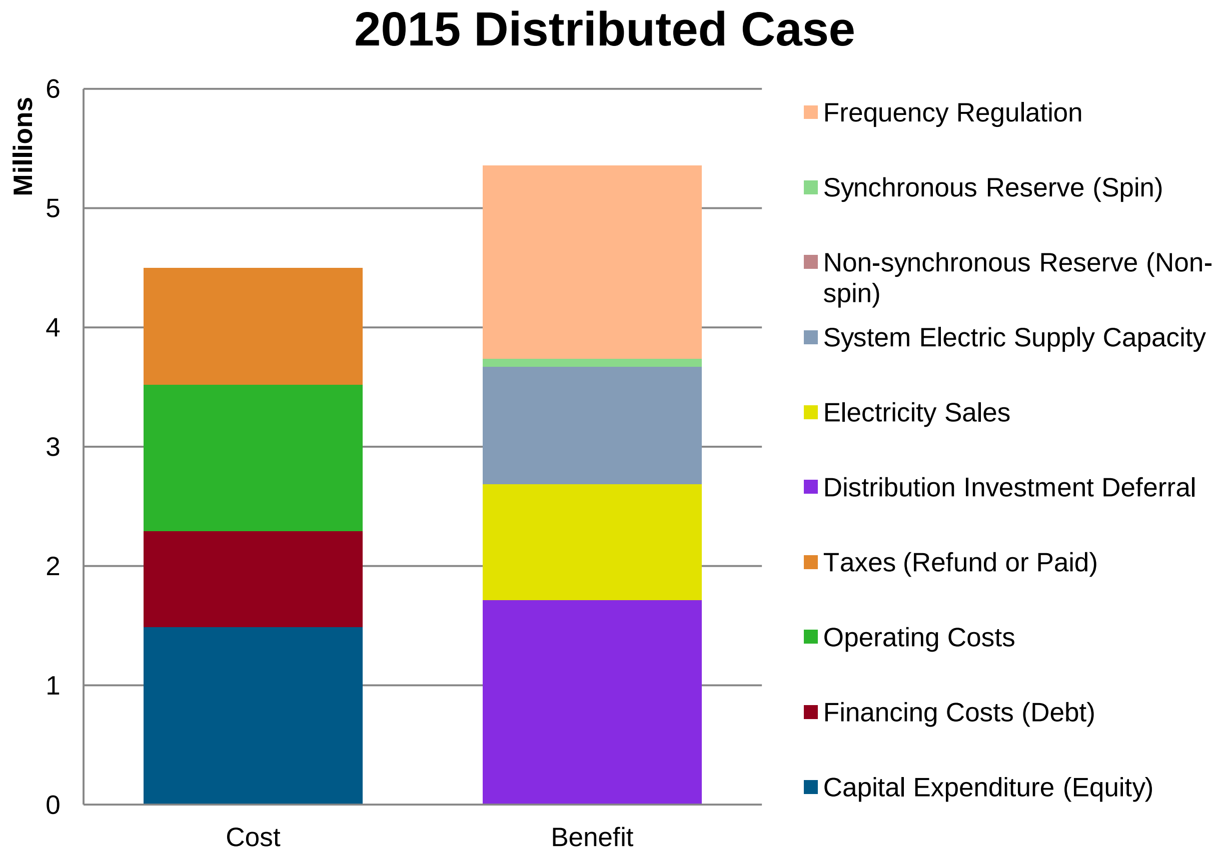
Distributed Storage at Substation Base Case Assumptions Provided by CPUC

- Key technology cost / performance assumptions

Category	Input	2020	2015	
		Battery (4hr)	Battery (4hr)	Flow Battery (4hr)
Technology Cost / Performance	Nameplate Capacity (MW)	1	1	1
	Nameplate Duration (hr)	4	4	4
	Capital Cost ($/kWh) -Start Yr Nominal	437	500	775
	Capital Cost ($/kW) - Start Yr Nominal	1750	2000	3100
	Project Life (yr)	20	20	17
	Roundtrip Efficiency	83%	83%	70%
	Variable O&M ($/kWh)	0.00025	0.00025	0.00025
	Fixed O&M ($/kW-yr)	15	15	15
	Major Replacement Frequency	1	1	0
	Major Replacement Cost ($/kWh)	250	250	-
	MACRS Depreciation Term (yr)	7	7	7

Distribution Storage at Substation Cost-Effectiveness Result for Base Case

- **Benefit/Cost Ratio** = 1.19
- **Breakeven Capital Cost:** $851/kWh ($3403/kW) in 2013 inflation adjusted dollars



Base Case Inputs

Year 2015

1MW, 4hr (battery)

CapEx = $2000/kW, $500/kWh

11.5% discount rate

83% RT Efficiency

Energy & A/S prices escalated 3%/yr from CAISO 2011

$279/kW upgrade cost

2% load growth rate

Distribution Base Case: Project Start Year 2015 vs. 2020

	Base Case (2015)	Base Case (2020)
Breakeven Capital Cost in 2013 dollars	$851/kWh ($3403/kW)	$914 /kWh ($3656/kW)

<u>Base Case Inputs</u>

1MW, 4hr (battery)

CapEx = $2000/kW, $500/kWh

11.5% discount rate

83% RT Efficiency

Energy & A/S prices escalated 3%/yr from CAISO 2011

$279/kW dist. upgrade cost

2% load growth rate

<u>2020 Case Inputs</u>

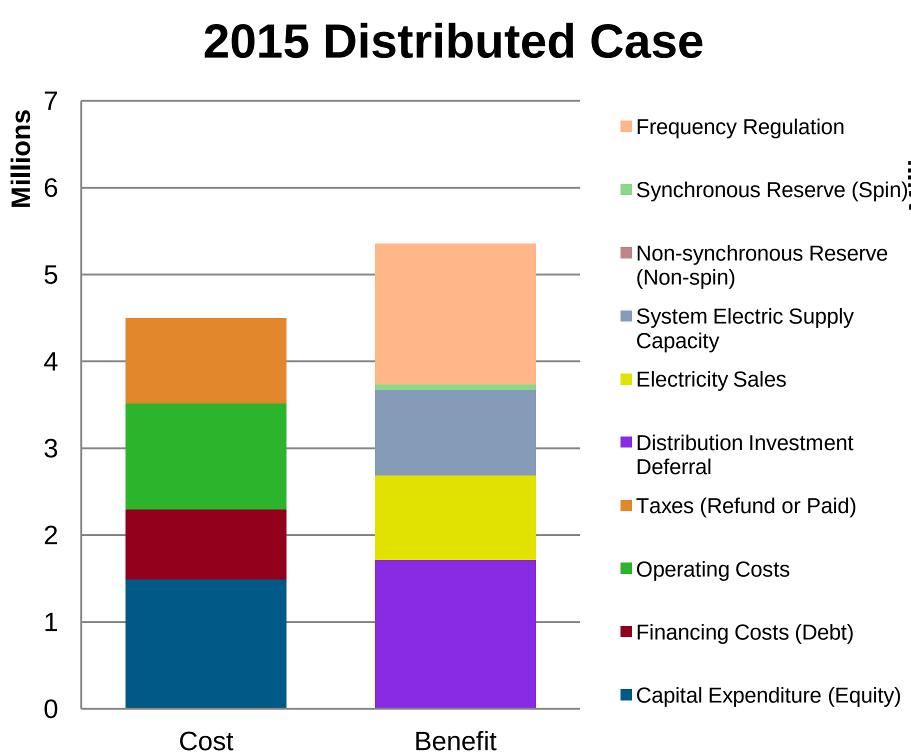
CapEx = $1750/kW, $438/kWh

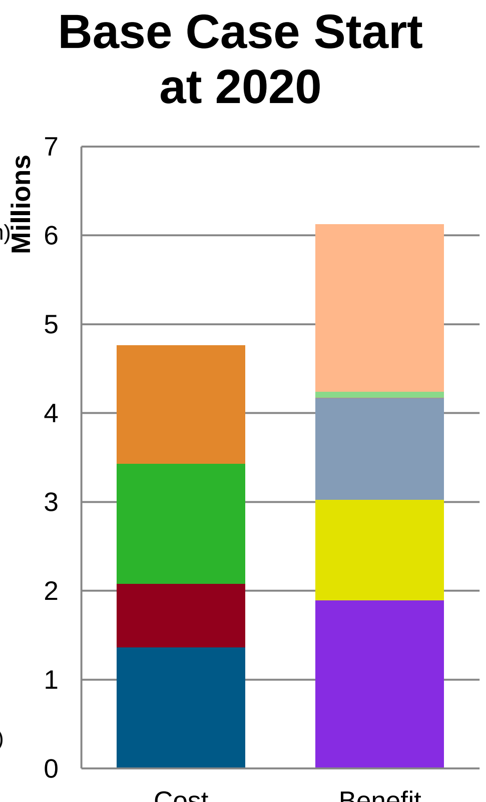
Same battery performance as base

$309/kW upgrade cost

2% load growth rate

Same market inputs as 2020 peaker use case base





Sensitivity to Distribution Base Case - Duration 4hr vs. 2hr

	Base Case (4 Hour)	Base Case (2 Hour)
Breakeven Capital Cost in 2013 dollars	$851/kWh ($3403/kW)	$1490 /kWh ($5960/kW)

<u>Base Case Inputs</u>

1MW, 4hr (battery)

CapEx = $2000/kW, $500/kWh

11.5% discount rate

83% RT Efficiency

Energy & A/S prices escalated 3%/yr from CAISO 2011

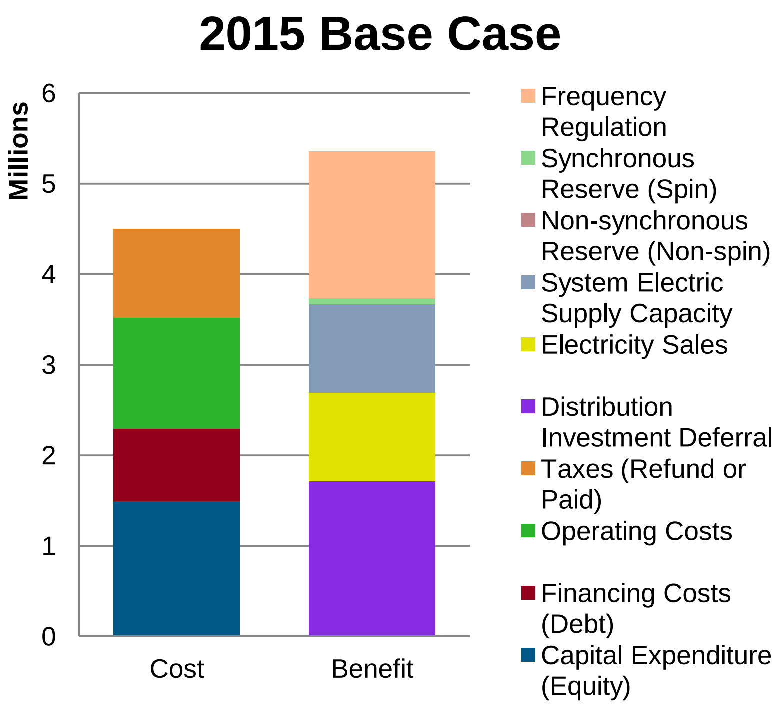
$279/kW upgrade cost

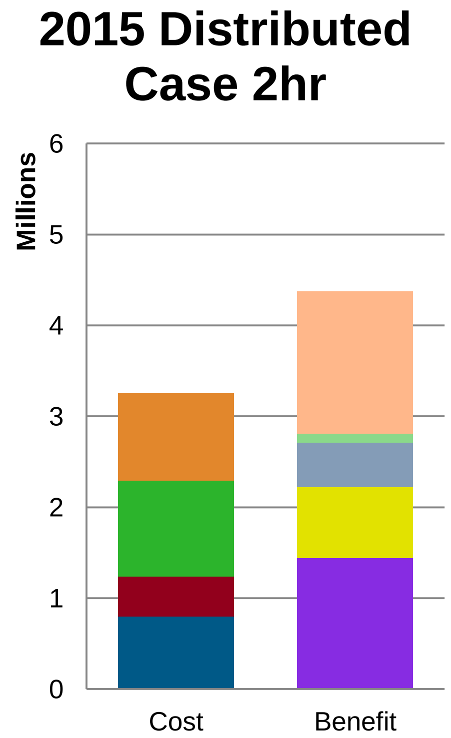
2% load growth rate

<u>2 hr Inputs</u>

1MW, 2hr

CapEx = $1100/kW, $550/kWh





Sensitivity to Regulation Price 2X multiplier

	Base Case	Base Case (2x Reg)
Breakeven Capital Cost in 2013 dollars	$851/kWh ($3403/kW)	$1307 /kWh ($5528/kW)

Base Case Inputs

1MW, 4hr (battery)

CapEx = $2000/kW, $500/kWh

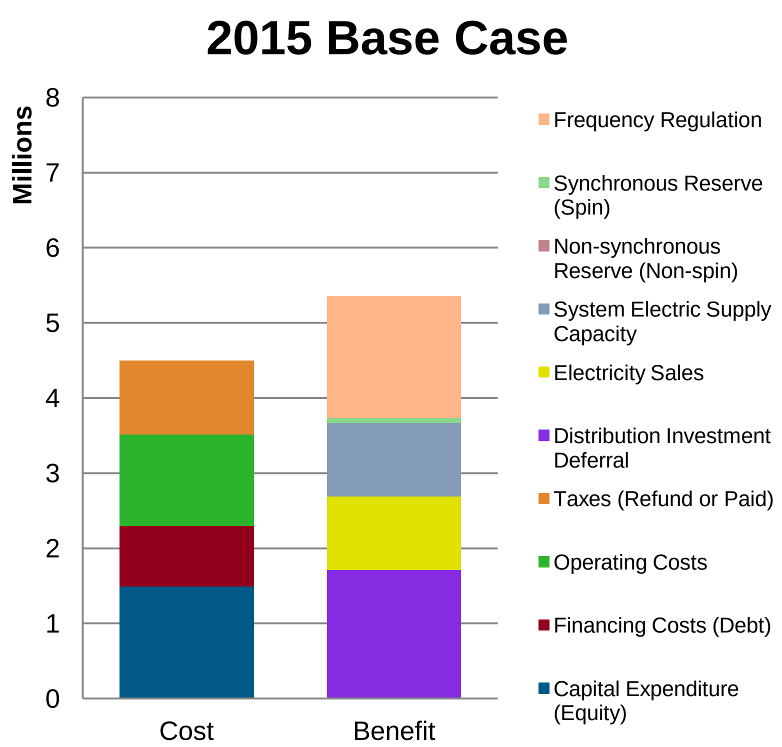
11.5% discount rate

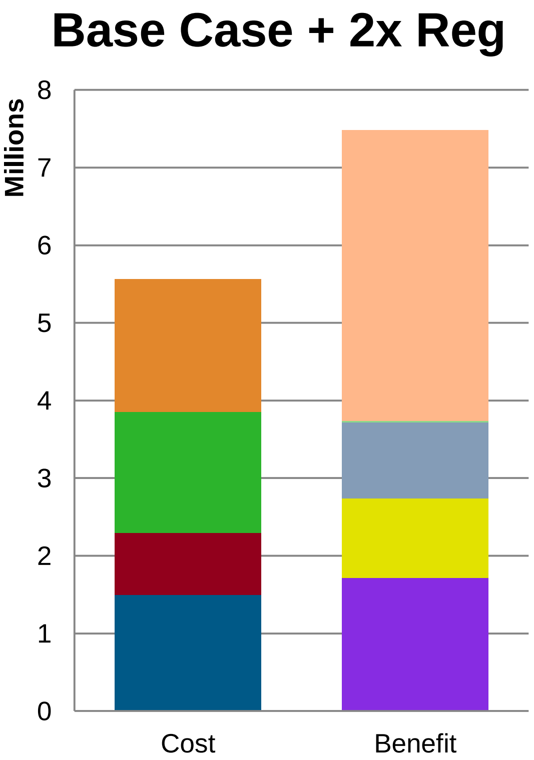
83% RT Efficiency

Energy & A/S prices escalated 3%/yr from CAISO 2011

$279/kW upgrade cost

2% load growth rate





Sensitivity Distribution Load Growth: 2% vs. 4%

	Base Case (2%)	Base Case (4%)
Breakeven Capital Cost in 2013 dollars	$851/kWh ($3404/kW)	$619 /kWh ($2476/kW)

Base Case Inputs

1MW, 4hr (battery)

CapEx = $2000/kW, $500/kWh

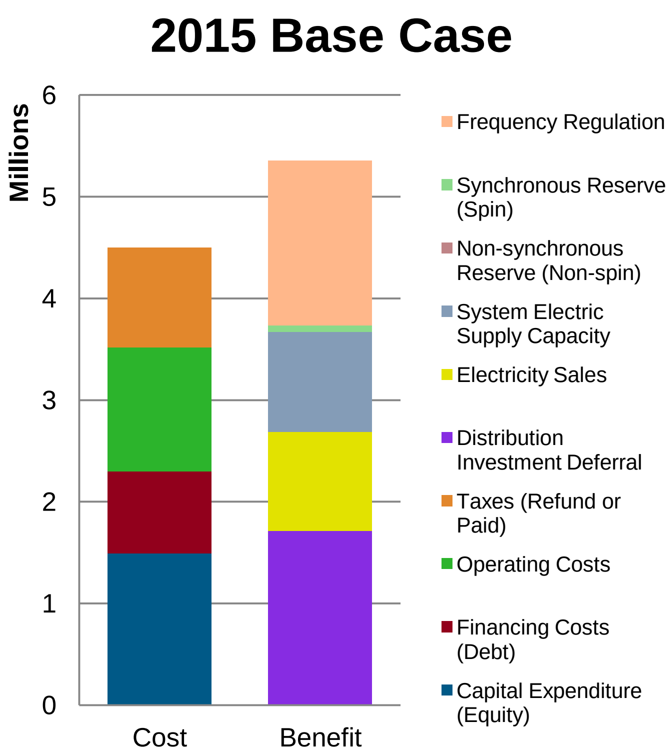
11.5% discount rate

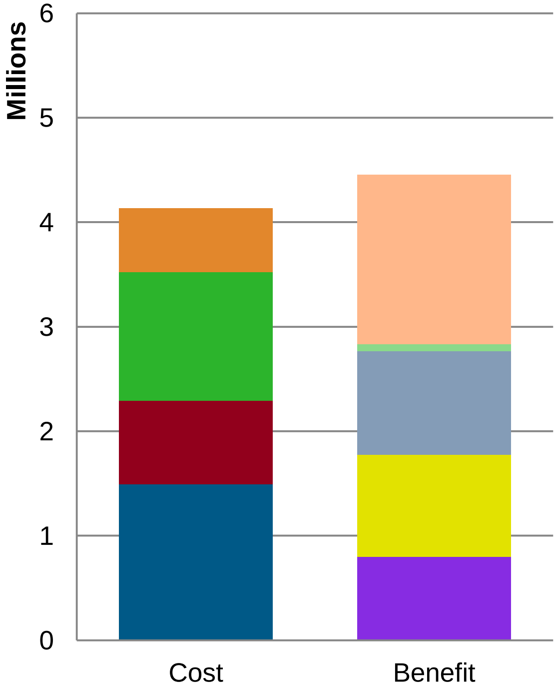
83% RT Efficiency

Energy & A/S prices escalated 3%/yr from CAISO 2011

$279/kW upgrade cost

2% load growth rate





Storage Comparison: Battery (Base) vs. Flow Battery

	Base Case	Base Case w/ Flow Battery – 4h
Breakeven Capital Cost in 2013 dollars	\$851/kWh (\$3403/kW)	\$1000 /kWh (\$4000/kW)

<u>Base Case Inputs</u>

1MW, 4hr (battery)

CapEx = \$2000/kW, \$500/kWh

11.5% discount rate

83% RT Efficiency

Energy & A/S prices escalated 3%/yr from CAISO 2011

\$279/kW upgrade cost

2% load growth rate

<u>Flow Battery Inputs</u>

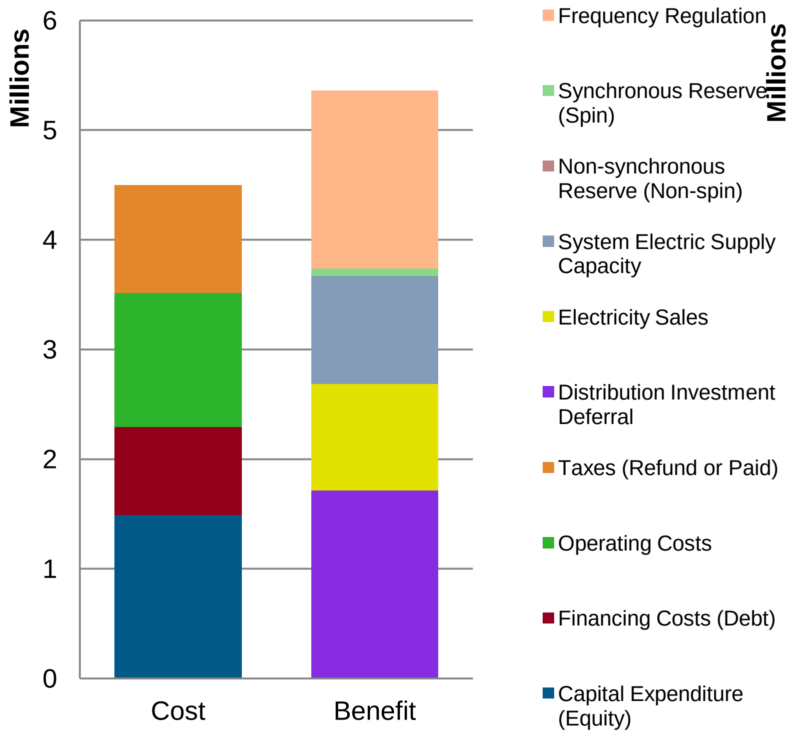
1MW, 4hr

17 yr project life

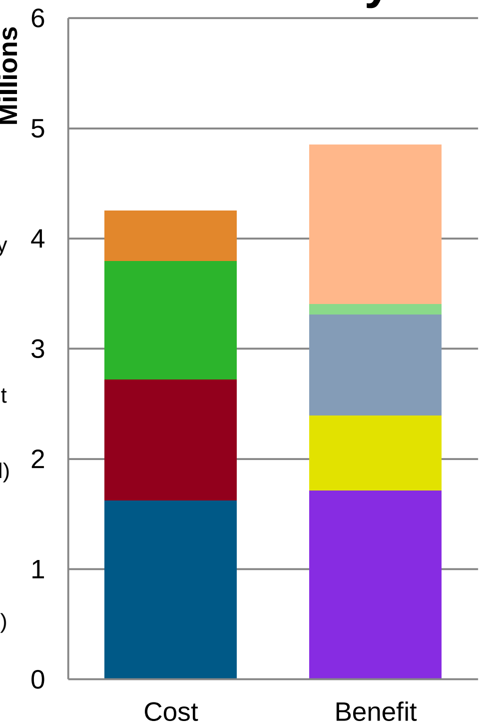
CapEx = \$3100/kW, \$775/kWh

No replacements

2015 Base Case



Base Case with Flow Battery



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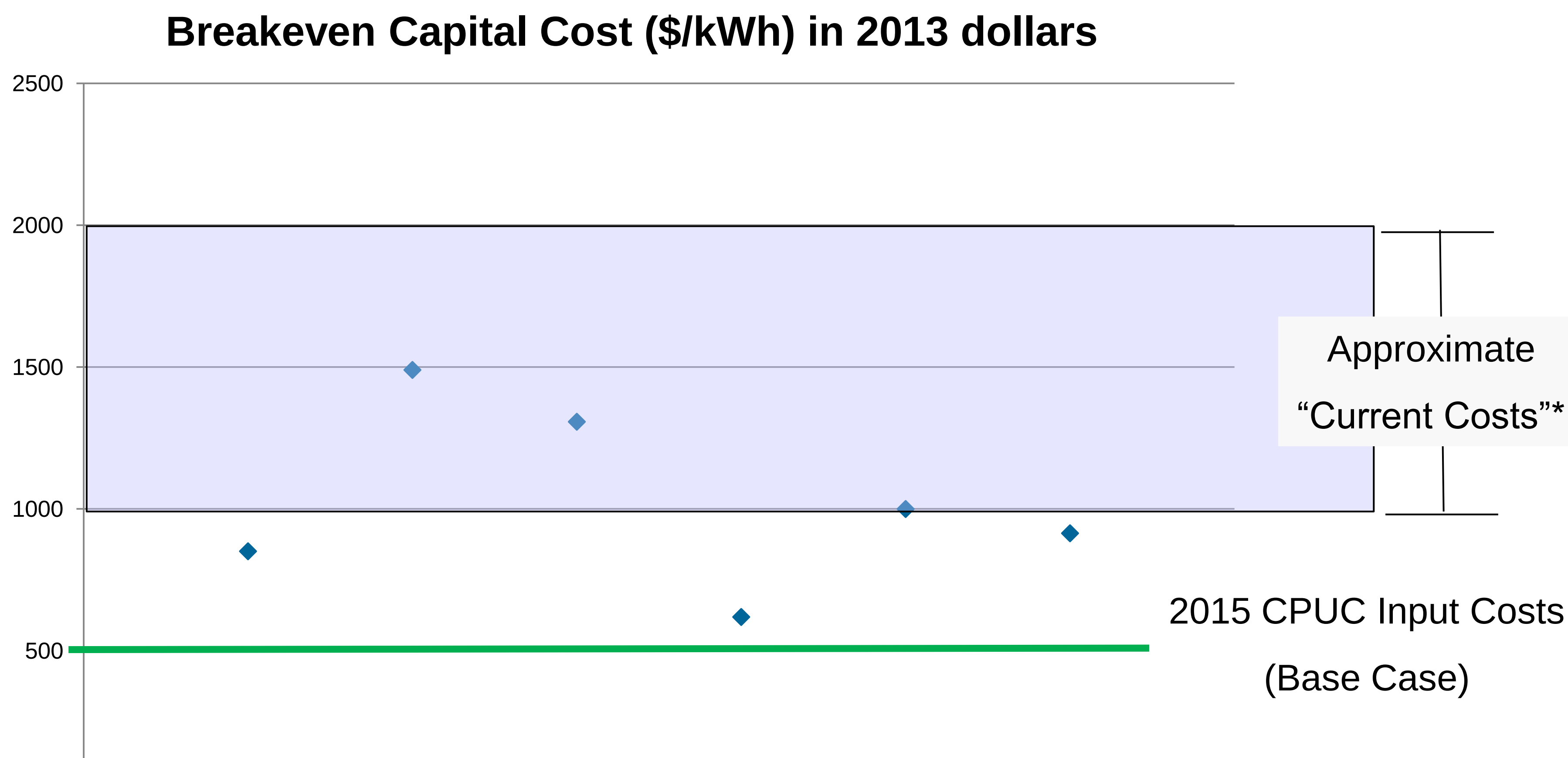
Overview of Distribution Results: Breakeven Capital Costs

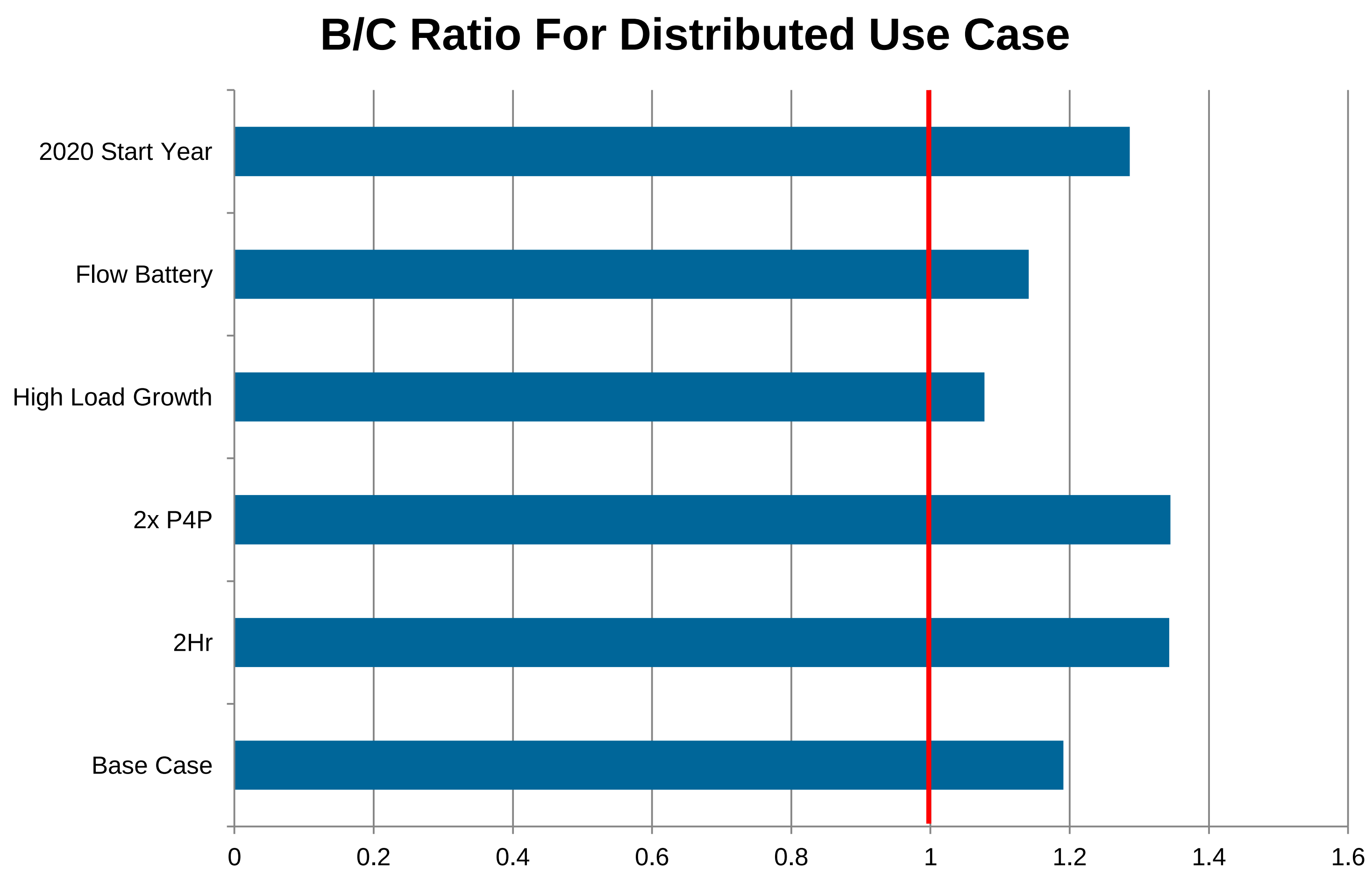


All Cases Cost-Effective with CPUC Inputs; Few Cases Cost-Effective at Current Costs**

* Based on 2011 EPRI Storage Cost Survey and other sources

** "Current costs" applicable to 2-4hr battery, not other technologies contained

Overview of Distribution Case: Benefit-Cost Ratio with CPUC Inputs



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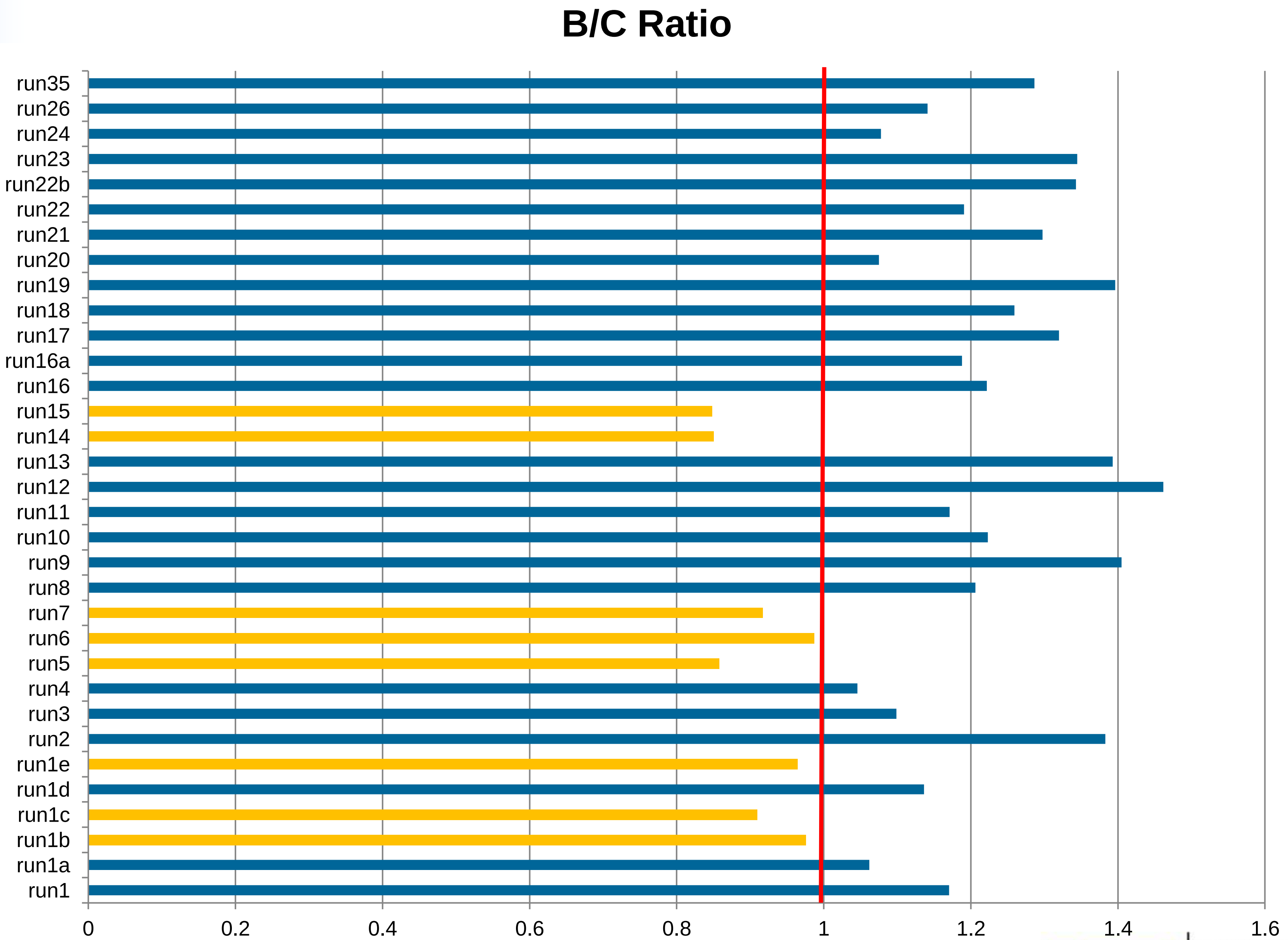
Conclusions & Next Steps

Overview of all Benefit-to-Cost Ratios



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Overview of findings

- Key findings from modeling analysis
  - Under provided assumptions, no clear conclusions between cost-effectiveness of different storage tech
  - Shorter duration typically allows for higher breakeven costs and improved benefit-to-cost ratios
  - Regulation is valuable for storage and price multiplier (pay-for-performance) drives battery storage profitability significantly
  - System capacity and T&D investment deferral are high value services
  - Higher Energy & A/S price escalation assumptions drive higher values in storage

***Reminder*: Results provided are valid only under stated CPUC assumptions.**

Conclusions

- In this analysis, ESVT calculated that storage is cost-effective under most of the scenarios defined by the CPUC
- Storage still faces significant challenges in terms of integration and deployment in the field
- Cost targets for storage defined in these scenarios have yet to be achieved

***Reminder*: Results provided are valid only under stated CPUC assumptions.**

Next Steps – Comments and Reporting

- We would love to hear your comments and feedback to this analysis
- Intend to produce a publicly available EPRI report in the June timeframe to more formally present the results of this analysis
  – Opportunity to incorporate FAQ's from stakeholders and clarifications

- **Analysis is still at an early stage! Case runs were completed in a short amount of time. More analysis pending.**

Thank you!

- Active participation from CPUC, CESA, PG&E, SCE, and SDG&E to support our input clarification questions and format inputs in a way that resulted in only a small number of miscommunications
  - Special thanks to Giovanni Damato of CESA for managing the input template
- Great feedback on important tool outputs and formats that will be incorporated into future versions of the ESVT.

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